U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-289 123

Emission Inventory/Factor Workshop. Volume II

(U.S.) Environmental Protection Agency, Research Triangle Park, NC

May 78

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-78-042b
May 1978

Air

PB 289123

EPA

Emission Inventory/ Factor Workshop

Volume 2

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-450/3-78-042b

2.

3. RECIPIENT'S ACCESSION NO.
PB289123

4. TITLE AND SUBTITLE
Emission Inventory/Factor Workshop Volume II

5. REPORT DATE
May 1978

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Various

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Air Pollution Training Institute
Air Management Technology Branch
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Same

13. TYPE OF REPORT AND PERIOD COVERED
Final Proceedings

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Moderator: James Southerland

16. ABSTRACT

This report in two volumes presents the written form and summarized discussions of "presentations" made at the Emission Inventory and Factor Workshop in Raleigh, N.C. September 13-15, 1977. A total of twenty-five "papers" on emission inventory and factor experiences and other information with emphasis on organics (hydrocarbons) were presented. Authors represented EPA, state air pollution control agencies and private industry.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Emission inventory Emission factors Volatile organic compounds Oxides of nitrogen Natural organic emissions State implementation plans		

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unrestricted	21. NO. OF PAGES 410
	20. SECURITY CLASS *(This page)* Unrestricted	22. PRICE PC A18 / MF A01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-450/3-78-042b

Emission Inventory / Factor Workshop

Volume 2

Moderator

James H. Southerland
OAQPS,
Monitoring Data and Analysis Division

Co-Moderators
Richard Burr
OAQPS,
Emission Standards and Engineering Division

Dale Denny
ORD,
Industrial Environmental Research Laboratory

Charles Masser
OAQPS,
Monitoring Data and Analysis Division

September 13-15, 1977
Raleigh, NC

Co-Sponsored by
Air Pollution Training Institute and Air Management Technology Branch

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

May 1978

1a

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - in limited quantities - from the Library Services Office (MD-35), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

USEPA

This is not an official policy and standards document. The opinions, findings, and conclusions are those of the authors and not necessarily those of the United States Environmental Protection Agency. Any mention of products, or organizations, does not constitute endorsement by the United States Environmental Protection Agency.

FOREWORD

Emission inventories and emission factors are major components of an air pollution control program. The inventory is perhaps one of the most important planning tools available to an air pollution control agency. Emphasis on these inventories and factors, the procedures used, and the use of the information has often been lacking, however. On September 13-15, 1977, the Office of Air Quality Planning and Standards hosted a workshop with both prepared topics and open discussion in Raleigh, N. C. to focus attention to some of the aspects of such emission inventory and factor activities particularly as related to the timely aspect of organic emissions. This document constitutes the proceedings of that workshop and will be distributed to the approximately 130 attendees. Additional copies are available from EPA Library Services Office.

Papers prepared for and presented at the workshop have been finalized by the authors and are included with no additional editorial or technical modifications. Papers presented do not necessarily represent policies of the Agency but may provide a basis for development or discussion of such policies. The workshop also provided a forum for various criticism which may appear to be unanswered but hopefully helped to create an open atmosphere conducive to constructive change.

The discussions during and following the papers were condensed and edited to the extent possible. Many important discussions may have been left out due to inadequate clarity of the recording and transcription. Some of the topics of discussion may also have been more clearly addressed by the authors when the final manuscripts were prepared. It was felt, however, to be worthwhile to include the condensed discussions to indicate where the attendees felt emphasis or clarification were needed.

Following this workshop the Air Pollution Control Association's (APCA) newly formed committee; TP-7: Emission Factors and Inventories, developed plans for an APCA Specialty meeting on Inventories and Factors which will be held in Anaheim California the week of November 13, 1978, and hosted by the West Coast, APCA Section. Participants at this workshop are especially invited to submit papers for possible presentation at the meeting in California and/or be present to participate in the discussion. It has been suggested that the concept of a forum for this general topic become an annual undertaking of EPA and/or APCA. Discussion of this point and general comments on the content of this document or the need for an annual conference of some sort can be addressed to the Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, N. C. 27711. More detail on specific papers would best be obtained by directly contacting the author(s).

As prime moderator of the workshop, I would like to express my thanks to the Air Pollution Training Institute and their contractor Northrop Services, Inc. who provided the arrangements, taping, transcription, and related work that made the workshop possible. Especially, I would like to thank the authors, co-moderators and attendees for their hard work and participation which made the workshop, I feel, to be a success.

James H. Southerland

James H. Southerland, Moderator.

Table of Contents

Emission Inventory/Factor Workshop
Volume 1

Foreword iii

1 Organic Emission Inventory Considerations and Purposes
C.P. Bartosh, W.J. Moltz, and B.P. Cerepaka 1-1 to 1-14

2 Analysis of Data for Hydrocarbon Sources in Non-Attainment Areas in Louisiana
B.C. McCoy and K.J. Guinaw 2-1 to 2-40

3 Documentation of Emission Inventories in Region IX
D.C. Henderson 3-1 to 3-14

4 Methodologies and Problems Encountered in a Level 3 Multi-State/County Hydrocarbon Area Source Emissions Inventory
T.A. Trapasso and W.K. Duval 4-1 to 4-26

5 Air Force Emission Inventories
B.C. Grems 5-1 to 5-14

6 A Format for the Storage of Area Source Emission Data
S.R. Tate, N.L. Matthews, D.J. Ames
R.A. Bradley 6-1 to 6-35

7 Maryland Special Factors and Inventory Techniques
E.L. Carter and J.W. Paisie 7-1 to 7-22

8 Panel Discussion of Inventory Methodology Procedures and Applications to Oxidant Control 8-1 to 8-26

Preceding page blank

9 Hydrocarbon Emissions from Households in New York and New Jersey
E.Z. Finfer
9-1 to 9-20

10 Hydrocarbon Carrier Emissions from Atmospheric Dye Becks
R. Hawks
10-1 to 10-25

11 Air Quality and Energy Conservation Benefits From Using Emulsions to Replace Asphalt Cutbacks in Certain Paving Operations
F.M. Kirwan
11-1 to 11-21

12 Commercial Bakeries as a Major Source of Reactive Volatile Organic Gases
D.C. Henderson
12-1 to 12-18

13 Reactive Organic Gas Emissions from Pesticide Use in California
F.J. Wiens
13-1 to 13-53

Emission Inventory/Factor Workshop
Volume 2

14 Volatile Organic Compound Emissions From Architectural Coatings
R.A. Friesen, R.E. Menebroker, D.K. Saito
14-1 to 14-12

15 NO$_x$ Reducations in the Portland Cement Industry with Conversion to Coal-Firing
R.J. Hilovsky
15-1 to 15-26

16 Current API Emission Measurement Programs
J.G. Zabaga
16-1 to 16-26

17 Hydrocarbon Emissions From Floating Roof Storage Tanks
R.L. Russell
17-1 to 17-22

18 Emission Inventory of Petroleum Storage and Handling Losses (A Case History)
J.T. Alexander
18-1 to 18-29

19 Inventorying Hydrocarbon Emissions From Small Gasoline Bulk Plants 19-1 to 19-39
R.L. Norton and R.J. Bryan

20 An Organic Specie Emission Inventory for Stationary Sources in the Los Angeles Area - Methodology 20-1 to 20-49
H.J. Taback, T.W. Sonneschen, N. Brunetz, and J.L. Stredler

21 Highway Motor Vehicle Emission Factors 21-1 to 21-80
Motor Vehicle Manufacturers Association of the United States, Inc.

22 FTP Emission Factor Development: Correction for Non-FTP Conditions 22-1 to 22-34
J. Becker and M. Williams

23 Land Use Based Emissions Factors 23-1 to 23-27
F. Benesh and T. McCurdy

24 Emission Rates for Biogenic NO_x 24-1 to 24-28
H.C. Ratsch and D.T. Tingey

25 Procedures for Conducting Hydrocarbon Emission Inventories of Biogenic Sources and Some Results of Recent Investigations 25-1 to 25-32
P. Zimmerman

VOLATILE ORGANIC COMPOUND
EMISSIONS FROM ARCHITECTURAL COATINGS

Prepared by,

Ronald A. Friesen
Raymond E. Menebroker
Dean K. Saito

Presentation Given at the
Emission Inventory/Factor Workshop
Sponsored by the
Environmental Protection Agency
September 14, 1977

ABSTRACT

By using the data in this paper, estimates can be made of Volatile Organic Compound (VOC) emissions from the use of architectural coatings and associated solvents. These emissions contribute significantly to air pollution in California. In an effort to reduce these emissions, the staff of the California Air Resources Board (CARB) developed a model rule to regulate the solvent content of architectural coatings. Essential to the development of the model rule was a data base. This data base was established by use of responses to questionnaires that were mailed to coatings manufacturers. These responses provided data on the sales volume of coatings and solvents and the VOC content of these coatings and solvents for a given year, 1975. With this data, the CARB staff determined the level of VOC emissions in California for 1975. In addition, by dividing the level of VOC emissions by the 1975 population of California, the CARB staff has devised a method to estimate VOC emissions when sales data are not known. Thus, two methods of computing VOC emissions are given in this document, and for each method, the effect of the model rule is shown.

VOLATILE ORGANIC COMPOUND EMISSIONS FROM ARCHITECTURAL COATINGS

by R. Friesen, R. Menebroker, D. Saito

Introduction

Little information has been generated with regard to emissions of Volatile Organic Compounds (VOC) from the use of architectural coatings. The staff of the California Air Resources Board has conducted an extensive inventory of such emissions in California, and the data gathered are presented herein. Using the data contained in this paper it is possible to estimate emissions from the use of architectural coatings with varying degrees of accuracy depending on the preciseness of information available. Such information includes population, total gallons of architectural coatings sold, or gallons of architectural coatings sold by coating category.

The methods of computing VOC emissions, presented here, are preceded by brief explanations of the research involved and the background of the study.

Background

Volatile Organic Compound emissions from the use of architectural coatings are a significant contributor to the air pollution problem in California. Based on this fact the California Air Resources Board (CARB) embarked on a program to control such emissions.

As part of this program, on July 7, 1977, CARB approved a model regulation to control emissions of VOC from the use of architectural coatings. The data base upon which an architectural coating rule could be developed, however, was nonexistent prior to CARB activity in this area. The first step in developing a rule, therefore, was to establish a sound data base. Recognizing this need, CARB staff developed a questionnaire that would ascertain the volumes of various waterborne and solvent-borne coatings sold in California and the VOC content of each. The VOC was requested by average and maximum for each coating category for the 1975 calendar year.

Industry Survey

The questionnaire was mailed to 446 potential paint manufacturers, 260 of which responded. Of these, 122 completed the questionnaire, and 138 reported that they did not manufacture architectural coatings. The responses received indicated that about 50 million gallons of architectural coatings were sold in California in 1975. A national sales survey prepared for the National Paint and Coatings Association indicates that about 435 million gallons of coatings were sold throughout the United States and that approximately 10 percent of the nationwide total, or 43.5 million gallons, was sold in California. A comparison of the two estimates indicates that the CARB survey is reasonably complete. The results of the CARB conducted industry survey are presented in Table I.

Table 1

Architectural Coatings Sales and VOC Emissions In California in 1975

COATING TYPE	1975 SALES (10^3 GAL)		EMISSIONS (TONS/DAY)*		
	Solvent Borne	Water Borne	Solvent Borne	Water Borne	Total
Interior Wall	2572	11445	12.0	5.4	17.4
Exterior Wall	1694	8375	7.1	5.4	12.5
Aerosols	1940	-0-	13.4	-0-	13.4
Roof	2316	2854	10.1	-0-	10.1
Clears	1820	18	9.4	0.008	9.4
Stains	1368	1205	8.0	1.3	9.3
Primers, Sealers and Undercoats	1617	1084	7.0	.69	7.7
High Performance Topcoats	1678	27	7.3	0.03	7.3
Traffic	1604	44	7.1	0.03	7.1
Sash, Trim and Trellis	1182	891	4.6	1.3	5.9
Metallic Pigmented	492	3	2.6	.001	2.6
Porch, Deck and Floor	498	339	2.5	0.1	2.6
High Performance Primers	294	15	1.4	0.007	1.4
Barn and Fence	100	298	0.4	0.1	0.5
Mobile Home	48	4	0.2	0.005	0.2
Not Classified	1707	2604	8.2	1.5	9.7
Subtotal	20930	29216	101.3	15.9	117.2
Other Solvent**		-0-	69.0	-0-	69.0
Total	28781	29216	170.3	15.9	186.2

* From thinning and cleaning up.

VOC Content of Architectural Coatings

Average VOC content and range of VOC content by volume for various coating categories are listed in Table 2. The average VOC contents listed in Table 2 are weighted by sales in each category. The ranges given are the lowest and highest maximum VOC content indicated on the returned questionnaires.

Low-solvent coatings are essentially waterborne latex (or emulsion) types, although water-dispersion type coatings, which are partially soluble in water and organic solvent mixtures, are not becoming commercially available.

While latexes do contain some VOC, concentrations are usually much less than in solvent-type coatings. Average VOC concentrations are eight percent by volume for latexes and 54 percent by volume for solvent-borne coatings.

From the returned questionnaires the staff was able to use the sales data and the weighted average solvent content to assess the emissions of VOC from each coating category. The VOC content for each coating category was calculated by multiplying the volume of coatings sold by the average VOC content. For each specific coating category the total of these estimates yields the volume of VOC released to the atmosphere. The volume of emissions was converted to weight by multiplying by the appropriate density (6.5 pounds per gallon for solvent used in solvent-borne coatings; 8.6 pounds per gallon for solvents used in waterborne coatings). The total weight

Table 2

Average VOC Content and Range of VOC Content for Various Architectural Coating Categories

Architectural Coating Category	Average VOC (%)		Range of VOC (%)	
	Solvent Borne	Water Borne	Solvent Borne	Water Borne
Exterior Wall	47	10	17-66	1-15
Interior Wall	52	7	30-75	2-38
Roof	49	8	33-80	0-10
Sash, Trim, and Trellis	44	13	17-75	3-23
Barn and Fence	45	4	26-68	1-39
Porch, Deck, and Floor	56	3	48-83	.3-5
Mobil Home	47		35-71	.3-5
Traffic	50		25-76	1.5-5
Primers, Sealers and Undercoaters	50	9	20-92	.1-32
Stains	66	9	50-95	2-36
Clears	58		35-95	2-77
Metallic Pigmented	59		43-80	1.4-74
Aerosals	78	0	48-99	---
High Performance Primers	53		36-94	3.6-17
High Performance Topcoat	49		49-90	1-36
Not Classified	54	5		
Overall Average	54	8		

per year was converted to an average emission rate in tons per day (TPD) based on 365 days per year. The total VOC emissions from the use of architectural coatings was determined to be 117 TPD in 1975 in California.

VOC emissions from thinning and cleanup was accounted for based on an average of one-half gallon of solvent per gallon of solvent-borne coating (except aerosols, roof, and traffic coatings). This figure is derived from estimates obtained from the industry and from local air pollution control districts. Estimates from the industry ranged from one gallon of thinner for each 10 gallons of coating to one to one. For traffic and roof coatings a ratio of one to five was used because these coatings are typically applied in large quantities, and their usage does not entail much solvent for cleanup. No solvent usage was assumed for cleanup and thinning of aerosols. The volume of solvents used for thinning and cleanup in California totaled over seven million gallons in 1975 or 69 TPD. Therefore, the total emission of VOC associated with the use of architectural coatings in California was 186 tons per day in 1975.

Emission Factors

Perhaps the most useful way of expressing findings in terms of an emission factor is pounds of VOC emitted per capita. Official State of California Department of Finance figures indicate that the state population as of January 1, 1975, was 21,030,245. Based on the 1975 data of VOC emissions of 186 tons per day, the California per capita emission factor for 1975 is therefore 6.5 pounds per capita.

Reasonably detailed emission inventories for emissions from architectural coatings have been conducted in California by the San Diego County and the San Francisco Bay Area Air Pollution Control Districts (APCDs) for 1975 and 1976 respectively. As can be seen from Table 3 the results of the Bay Area APCD survey compare favorably with the ARB survey. The San Diego County APCD survey is significantly different; no explanation of this discrepancy could be found.

Table 3

Comparison of Air Resources Board and San Diego and Bay Area Air Pollution Control Districts Inventories for Architectural Coatings

		Bay Area APCD	San Diego County APCD
Population*		4,767,032	1,541,500
Total VOC Emission (T/D)	APCD ARB	41 42.5	17.8 13.7
Yearly Per Capita Emissions (pounds)	APCD ARB	6.3 6.5	8.4 6.5

* Bay Area Inventory conducted for 1976, San Diego Co. Inventory conducted for 1975. Population figures from California Department of Finance, SB 90 population data.

Effect of ARB Model Rule on Emission Factor

As indicated earlier the Air Resources Board has developed a model regulation to control VOC emissions from the use of architectural coatings. The regulation limits the VOC content of architectural coatings to 250 grams per liter of coating less water except that interior coatings are permitted to contain 350 grams per liter of container less water. The following coatings are exempt until 1982:

1. Varnishes, lacquers, or shellacs;
2. Semitransparent stains;
3. Opaque stains on bare wood, cedar, fir, and mahogany;
4. Primers, sealers, and undercoaters;
5. Wood preservatives;
6. Fire retardant coatings;
7. Tile-like glaze coatings;
8. Waterproofing coatings;
9. Industrial maintenance finishes;
10. Metallic pigmented coatings;
11. Swimming pool coatings; and
12. Graphic arts coatings.

The emission reduction expected from the model rule is 53 tons per day in 1978. Potentially an emission reduction of 156 tons per day can be achieved in 1982 if adequate substitutes are available for those coatings which are initially exempted. These emission figures were derived based on the assumption that all solvent-borne coatings that are required to meet the model rule would be replaced by waterborne coatings of the same average VOC content as those waterborne coatings now in use. This assumption may be conservative, because many waterborne coatings currently contain more VOC than is allowed by the model rule. Implementing the model rule will bring about a reduction in the VOC content of waterborne coatings and an accompanying reduction in emissions attributable to such coatings. Therefore, the net reduction in VOC emissions will be greater than 53 tons per day, but exact figures cannot be determined at this time.

Based on a reduction of 53 tons per day, the total emissions of VOC to the atmosphere in 1975 would have been 133 tons per day instead of 186 tons per day if the model rule had been in effect. Therefore, the emission factor if the ARB's model rule had been in effect in 1975 would have been 4.6 pounds of VOC emitted per capita.

Summary

The level of VOC emissions from architectural coatings can be determined by using sales data or per capita emission factors.

When sales data are known for a state or anyother geographical area, the volume of solvent for each coating category can be calculated by multiplying the volume of coatings sold by the average solvent content. For each specific coating category the total of these estimates yields the volume of organic released to the atmosphere. The volume of emissions can then be converted to weight by multiplying by 6.5 pounds per gallon for the solvents used in solvent-borne coatings or 8.6 pounds per gallon for the solvents used in waterborne coatings. In addition, similar computations should be made to estimate the VOC emissions from the solvents used for thinning and cleanup, and these emissions should be added to the emissions attributable to the coatings.

Data compiled by the CARB indicate that in 1975 the VOC emissions attributable to architectural coatings was 117 TPD, and the VOC emissions from solvents used for thinning and cleanup was 69 TPD, thereby giving a total of 186 TPD. Had the model rule been in effect, the total would have been 133 TPD.

A quicker method, and one that works in the absence of sales data, is to compile VOC emissions on a per capita basis. According to figures compiled by the CARB and San Francisco Bay Area APCD, yearly per capita emissions from architectural coatings and the solvents used for thinning and cleaning approximately 6.5 pounds per capita without the model rule and 4.6 pounds with the model rule. Multiplying the per capita figure by state or area population will yield an annual emission amount that can be converted to TPD by dividing by 365 $\left(\frac{\text{days}}{\text{years}}\right)$ and 2000 $\left(\frac{\text{pounds}}{\text{ton}}\right)$.

Either method will yield acceptable accuracy when computing emissions of VOC associated with architectural coatings.

NO_x REDUCTIONS IN THE PORTLAND CEMENT INDUSTRY WITH CONVERSION TO COAL-FIRING

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

ROBERT J. HILOVSKY, P.E.
Supervisor, Source Test Section
Engineering Division, Eastern Zone
South Coast Air Quality Management District
Colton, California

Introduction

The cement industry is one of the nation's most energy-intensive industries - where more energy is consumed producing a dollar's worth of product than for any other major product. A report issued by the Cost of Living Council in 1973 shows that the energy cost for cement was 43 percent of the product. This figure has continued to rise with the increasing cost of fuel. The cement plants of Southern California have used natural gas as fuel, with oil as a standby energy source. The high availability of natural gas, ease of handling and its cheap cost compared to other fuels were the major factors for continuing its use. However, with the growing shortage of natural gas, estimates by the California Public Utilities Commission that no gas supplies will be available to major industries by 1980 and large price increases (38 percent in 1975) for gas, the cement industry began conversion to fuel oil and coal.

The South Coast Air Quality Management District (SCAQMD) has four cement companies (operating six different facilities) under its jurisdiction. All of these facilities are located in the Eastern Zone of the District, with five plants in San Bernardino County and one plant in Riverside County. The SCAQMD was formed on February 1, 1977, as a successor agency of the Southern California APCD. That APCD, in turn, had been formed on

July 1, 1975, from the Los Angeles, Orange, Riverside and San Bernardino County APCD's. All data referenced in this report was collected by the same group of personnel - although the organization changed names.

Background

The San Bernardino County APCD began source testing for NO_x emissions in 1969-70 for all industries in the county for both compliance and emission inventory information. The larger industries in the county were also tested on an annual basis, beginning in 1972. Variations in NO_x emissions from one facility were observed, but investigation as to the cause was not pursued at that time. The emission inventories showed that the cement industry comparatively was a very large NO_x emitter (Table I) in San Bernardino County.

TABLE I

NO_x Emissions from San Bernardino County Cement Plants

Facility	NO_x Emissions (Tons/Day)*
California Portland Cement Co., Colton	19.10
Riverside Cement Co., Oro Grande	25.66
Kaiser Cement & Gypsum Corp., Lucerne Valley	20.42
Southwestern Portland Cement Co., Victorville	7.0
Southwestern Portland Cement Co., Black Mountain	13.44
TOTAL	85.62

*Based on an average rate of 80% production, natural gas for fuel. NO_x is reported as NO_2.

Fuel Changes and Effects Upon Pollutants

Riverside Cement Company and California Portland Cement Company filed applications in 1974 with the District to convert their rotary kilns to coal-firing. Review of these applications, in considering the possible changes in emissions, led to the analysis of the data collected from source tests on cement kilns. Analysis of these data revealed:

(1) The sulfur in the fuel oil was absorbed in the clinker manufacturing process (as sulfates or sulfides) and only very small amounts of sulfur dioxide would be emitted to the atmosphere. It was expected, therefore, that the sulfur in the coal also would be absorbed and would not cause any violation (500 ppm limit) of the District's SO_2 rules.

(2) Existing air pollution control equipment could adequately control any increase in particulate matter expected from coal use.

(3) The use of fuel oil showed a reduction in NO_x emissions, compared to NO_x from natural gas.

It is believed that when burning fuel oil in the cement kiln that it can more readily be burned with a flame that is less oxidizing than the flame resulting from natural gas combustion. (It would appear to be a "lazy" flame pattern when viewed through flame ports.) With these differences in the kinetics of combustion in the kiln, the result is lower NO_x generation when burning fuel oil in the cement kiln - compared to natural gas. The use of coal for fuel should result in an even further reduction of NO_x emissions since it typically produces a longer, "lazier" flame (with lower temperature in the center of the flame) than does fuel oil combustion in the cement kiln. In reviewing applications from the cement plants, the "Permits to Construct" were approved since it was calculated that an overall reduction in emissions into our air basin would occur.

The conversion to coal was completed by November 1974 for the Riverside Cement Company and by May 1975 for the California Portland Cement Company. Southwestern Portland Cement Company and Kaiser Cement & Gypsum Corporation switched over from natural gas to fuel oil combustion in 1976. Source testing of these units has indicated that a substantial reduction occurred in NO_x emissions into the atmosphere.

TABLE II

NO_x Reductions in Cement Kilns
Due to Fuel Changes

FACILITY	NO_x EMISSIONS(1) (TONS/DAY)			PERCENT REDUCTION
	Gas	Oil	Coal	
California Portland Cement	19.10	4.58(2)	3.50	76(2)/81.7
Riverside Cement	25.66	----	7.75	69.7
Kaiser Cement & Gypsum	20.42	15.46	----	24.2
Southwestern Portland Cement (Victorville)	7.0	4.30	----	38.2
Southwestern Portland Cement (Black Mountain)	13.44	12.06	----	10.2
TOTAL	85.62	43.07		49.7

(1)Based on 80% production rate. NO_x is measured as NO_2.

(2)Not used at this facility since conversion to coal.

Table II shows that larger reductions in NO_2 emissions are accomplished with conversion to coal-firing versus oil-firing. With the growing scarcity of petroleum products, there would be more advantages in the long run for cement plants to convert to coal-firing (directly from natural gas) rather than to oil-firing; even though a conversion to oil-firing would somewhat reduce NO_x emissions into the atmosphere. Kaiser Cement & Gypsum Corporation has filed an application for coal conversion with the District, and Southwestern Portland Cement Company has approved funds for coal conversion.

Test Methods and Procedures

Two test methods were used in obtaining the data (Appendix A) presented in this report. The Phenoldisulfonic Acid (PDS) method, which is the approved California Air Resources Board and U. S. Environmental Protection Agency reference method, was used along with a continuous electrochemical cell analyzer (Envirometrics) and recorder. Both methods well complimented each other although the analyzer was not obtained until 1972. Some early PDS data was considered invalidated when it was indicated that NO_x concentrations were over 1,000 ppm. For NO_x values near or over 1,000 ppm, the chemist performing the PDS analysis must be aware of the potentially high concentration so proper steps in the preparation of aliquot portions can be taken to assure accuracy in the analysis.

The continuous analyzer revealed variations in emissions throughout the process operations (Figure 1). For example, the concentration range for one test was 950 to 1,650 ppm NO_x, with an average of 1,490 ppm. For this example, the PDS values could vary greatly depending upon when the "grab sample" was taken, with respect to hitting "peaks" or "valleys" in the NO_x versus time curve.

Emission Factors

The five plants tested have different configurations of exhaust gas ducting and different types of control systems. This resulted in different excess-air concentrations for each test site. To obtain a correlation of NO_x emissions into the atmosphere, emission factors were generated. These are listed in Tables III, IV and V and divided into categories dependent upon (1) fuel use, (2) type of process and (3) production rate.

Conclusions and Recommendations

Table VI is a summary of the emission factors generated, and Figures 2, 3 and 4 are plots of the emission factors versus kiln capacity. The following conclusions are indicated from this data:

(1) Emission factors vary greatly depending upon fuel, type of process and kiln size.

(2) There is a significant reduction in NO_2 emissions when either oil or coal is used for fuel, versus natural gas. It appears that greater reductions in emissions are available for coal-firing versus oil-firing (Table II).

(3) The emission factors for wet-process operations tend to be lower than for those with dry-process operations (Table VI).

(4) As the capacity of the kiln increases, the emission factor decreases for dry-process operations (Figures 2 and 3) while the reverse is indicated for wet-process operations (Figures 2 and 4). There can, however, be a larger NO_x variation between kilns of the same size - especially the smaller units (Figures 2 and 3).

(5) The emission factor and NO_x reduction from natural gas-firing versus oil-firing, for dry-process kilns of 100,000 lbs/hr of clinker, were much greater than for a 175,000 lbs/hr kiln (respectively 4.58 lbs/ton and 76% reduction versus 12.06 lbs/ton and 10.2% reduction).

(6) The NO_x emission factors depend upon a number of variables, and the use of only one factor should be discouraged in estimating NO_x emissions from cement kilns.

Some of the more important variables have been covered in this paper although other factors, such as diameter of kiln, length of fire zone and dwell-time before emitting into the atmosphere, should be investigated before developing a family of curves for cement kiln NO_x emission factors.

TABLE III

Emission Factors for Cement Kilns Using Natural Gas

Kiln	Raw Material Feed (1,000 lbs/hr)	Emission Factor (lbs. NOx/ton)	
		Raw Material Feed	Clinker
Dry Process Units*			
RC1	64	14.3	22.4
RC2	64	13.9	21.8
RC3	64	12.6	19.7
RC4	64	13.7	21.4
RC5	64	12.5	19.6
RC6	65.7	15.8	24.7
CP1	161	13.6	20.5
CP2	161	11.9	18.7
BM	264	10.9	16.9
BM	240	11.7	18.1
Wet Process Units			
SW5	29	18.7	28.9
SW6	39	3.9	6.1
	49	9.5	14.6
SW7	40	3.3	5.1
	50	5.2	8.1
SW8	38	5.6	8.6
	46	6.5	10.0
SW9	40	8.3	12.7
	41	15.3	23.6
KC1	92.4	3.2	5.0
KC2	92.4	4.1	6.4
KC3	184	6.6	10.3
	184	6.0	9.4

*RC = Riverside Cement, Oro Grande; CP = California Portland Cement, Colton; BM = Southwestern Portland Cement, Black Mountain; SW = Southwestern Portland Cement, Victorville; KC = Kaiser Cement & Gypsum, Lucerne Valley

TABLE IV

Emission Factors for Cement Kilns Using Fuel Oil

Kiln	Raw Material Feed (1,000 lbs/hr)	Emission Factor (lbs. NO_x/ton)	
		Raw Material Feed	Clinker
Dry Process Units			
CP1	168	1.6	2.6
	168	4.1	6.9
CP2	168	2.9	4.9
	168	2.8	4.6
BM	240	10.5	16.1
Wet Process Units			
SW7	49	3.7	5.7
SW8	49	7.9	12.2
SW9	41	2.3	3.5
KC1	92	2.8	4.4
	92	2.9	4.5
KC2	92	3.0	4.7
	92	3.1	4.8
KC3	184	5.1	7.9

TABLE V

Emission Factors for Cement Kilns Using Coal

Kiln	Raw Material Feed (1,000 lbs/hr)	Emission Factor (lbs. NO_x/ton)	
		Raw Material Feed	Clinker
Dry Process Units			
RC2	64	1.4	2.2
	64	3.6	5.7
RC3	64	4.4	6.9
	64	4.9	7.6
RC4	64	5.4	8.5
	64	5.6	8.6
RC5	64	6.2	9.7
	64	6.2	9.6
RC6	65.7	4.1	6.4
CP1	161	2.0	3.3
	171	2.9	4.7
CP2	159	2.4	3.7
	157	1.9	3.1

TABLE VI

Summary of NO_2 Emission Factors
for Cement Kilns (lbs. NO_x/ton of Clinker)

Fuel	Type of Cement-Manufacturing Process	Range	Average
Gas	Dry	16.9 to 24.7	20.4
Gas	Wet	5.0 to 28.9	11.5
Oil	Dry	2.6 to 16.1	7.0
Oil	Wet	3.5 to 12.2	5.9
Coal	Dry	2.2 to 9.7	6.2

APPENDIX A

TEST DATA USED FOR REPORT

Unit	Capacity Bbl/day	Test Date	Raw Material lbs/hr	Clinker Production Tons/hr	Fuel	Flowrate DSCFM	NO2 Emissions		Emission Factor	
							PPM	lbs/hr	Raw Material (lbs/ton)	Clinker
Dry Process										
CP1	6,500	12/28/76	151,000 (+ 20,400 coal)	50	Coal	138,555	220	221.9	2.94 (2.6)	4.7 (4.2)
		6/15/76	161,000	50	Coal	150,000	150	165.1	2.0	3.3
		10/12/73			Gas	140,500	1,000	1,023.2	13.5	20.5
		1/28/70	168,000		Oil	127,900	142	132.3	1.6	2.6
		4/28/70			Oil	127,900	372	346.5	4.1	6.9
CP2	6,500	12/28/76	159,000	50	Petroleum Coke & Oil	139,597	183	186.0	2.4	3.7
		6/15/76	157,780	49	Coal	135,000	157	154.7	1.96	3.1
		10/12/73			Gas	146,600	880	939.4	11.9	18.7
		4/28/70	168,000		Oil	188,041	178	243.7	2.9	4.9
		1/28/70			Oil	188,000	169	231.4	2.8	4.6

Unit	Capacity Bbl/day	Test Date	Raw Material lbs/hr		Fuel	Flowrate DSCFM	NO2 Emissions		Emission Factor	
							PPM	lbs/hr	Raw Material (lbs/ton)	Clinker
Wet Process										
KC1	4,000	3/5/76	136,400	Solids (92,300)	Oil	77,939	493	279.8	4.1 (2.8)*	6.4
					Oil	78,630	503	288.0	4.3	6.7
		5/2/72	142,588		Gas	60,933	770	341.7	4.8	7.5
KC2	4,000	12/14/76	136,137	Solids (92,300)	Oil	57,100	710	294.9	4.4 (3.0)*	
						57,012	780	324.0	4.8	7.5
		5/2/72	142,588		Gas	55,185	1,082	434.3	6.1	9.5
KC3	8,000	12/16/76	273,100	Solids (184,615)	Oil	119,072	1,180	1,023.0	7.5 (5.1)*	11.69
						108,443				
		10/15/73	292,786		Gas	99,600	2,000	1,450.6	9.9 (6.6)*	15.4
		5/2/72	276,255		Gas	90,973	1,880	1,245.5	9.0 (6.0)*	14.0

*Raw material feed of dry product excluding water

Unit	Capacity Bbl/day	Test Date	Raw Material lbs/hr	Clinker Production Tons/hr	Fuel	Flowrate DSCFM	NO2 Emissions PPM	NO2 Emissions lbs/hr	Emission Factor Raw Material (lbs/ton)	Emission Factor Clinker
Dry Process										
RC1	2,600	3/19/74			Gas	48,917	1,288	458.6	14.3	22.4
RC2	2,600	5/25/76	64,000	20.51	Coal	45,990	135	45.2	1.4	2.2
					Coal	44,478	360	116.6	3.6	5.7
		3/19/74			Gas	44,478	1,382 (1,050-1,640)	447.6	13.9	21.8
RC3	2,600	5/25/76	64,000	20.51	Coal	46,520	417	141.2	4.4	6.9
					Coal	40,295	535	156.9	4.9	7.6
		3/19/74			Gas	40,295	1,380 (990-1,520)	404.9	12.6	19.7
RC4	2,600	5/25/76	64,000	20.51	Coal	59,940	398	173.7	5.4	8.5
					Coal	~59,000	170	73.0	5.6	8.6
		3/19/74			Gas	~44,000	1,375 (1,160-1,400)	440.0	13.7	21.4
RC5	2,600	5/25/76	64,000	20.51	Coal	58,794	465	199.1	6.2	9.7
					Coal	58,800	460	196.9	6.2	9.6
		3/19/74			Gas	~43,900	1,128 (920-1,200)	401.6	12.5	19.6
RC6	3,000	11/12/75	63,000	20.19	Coal	44,462	400	129.5	4.1	6.4
	3,000	7/28/74	65,700	21.05	Gas	36,710 17,997	1,158 1,609	520.4	15.8	24.7

Unit	Capacity Bbl/day	Test Date	Raw Material lbs/hr	Clinker Production Tons/hr	Fuel	Flowrate DSCFM	NO2 Emissions PPM	NO2 Emissions lbs/hr	Emission Factor Raw Material (lbs/ton)	Emission Factor Clinker
Solids - Wet Process										
SW5	1,300	4/26/74	29,150	9.5	Gas	25,319	1,490 (950-1,650)	274.7	18.7	28.9
SW6	2,200	3/21/74	49,300	16.0	Gas	38,373	836 (700-900)	233.6	9.5	14.6
		5/12/70	39,720	12.9	Gas	29,681	362	78.2	3.9	6.1
SW7	2,200	5/12/70	40,610	13.1	Gas	30,948	297	66.9	3.3	5.1
		5/1/70	50,240	16.2	Gas	42,821	420	130.9	5.2	8.1
		4/29/76	49,318	16.0	Oil	38,240	330	91.9	3.7	5.7
SW8	2,200	5/12/70	38,610	12.5	Gas	27,747	535	108.1	5.6	8.6
		3/21/74	46,200	15.0	Gas	32,500	636	150.4	6.5	10.0
		4/29/76	49,641	16.1	Oil	40,900	659	196.3	7.9	12.2
SW9	2,200	3/21/74	40,400	13.1	Gas	36,333	631	166.9	3.3	12.7
		4/29/76	41,603	13.5	Oil	37,459	179	48.3	2.3	3.5
		6/11/75	41,600	13.5	Gas	36,200	1,212	319.4	15.3	23.6
Dry Process										
Blk Mtn	9,500	7/12/74	264,000	85.3	Gas	86,340	2,300	1,445.6	10.95	16.9
		6/11/75	240,000	77.5	Gas	86,340	2,230	1,401.6	11.68	18.1
		4/30/76	240,000	77.9	Oil	86,340	2,000	1,257.1	10.47	16.1

FIGURE 1

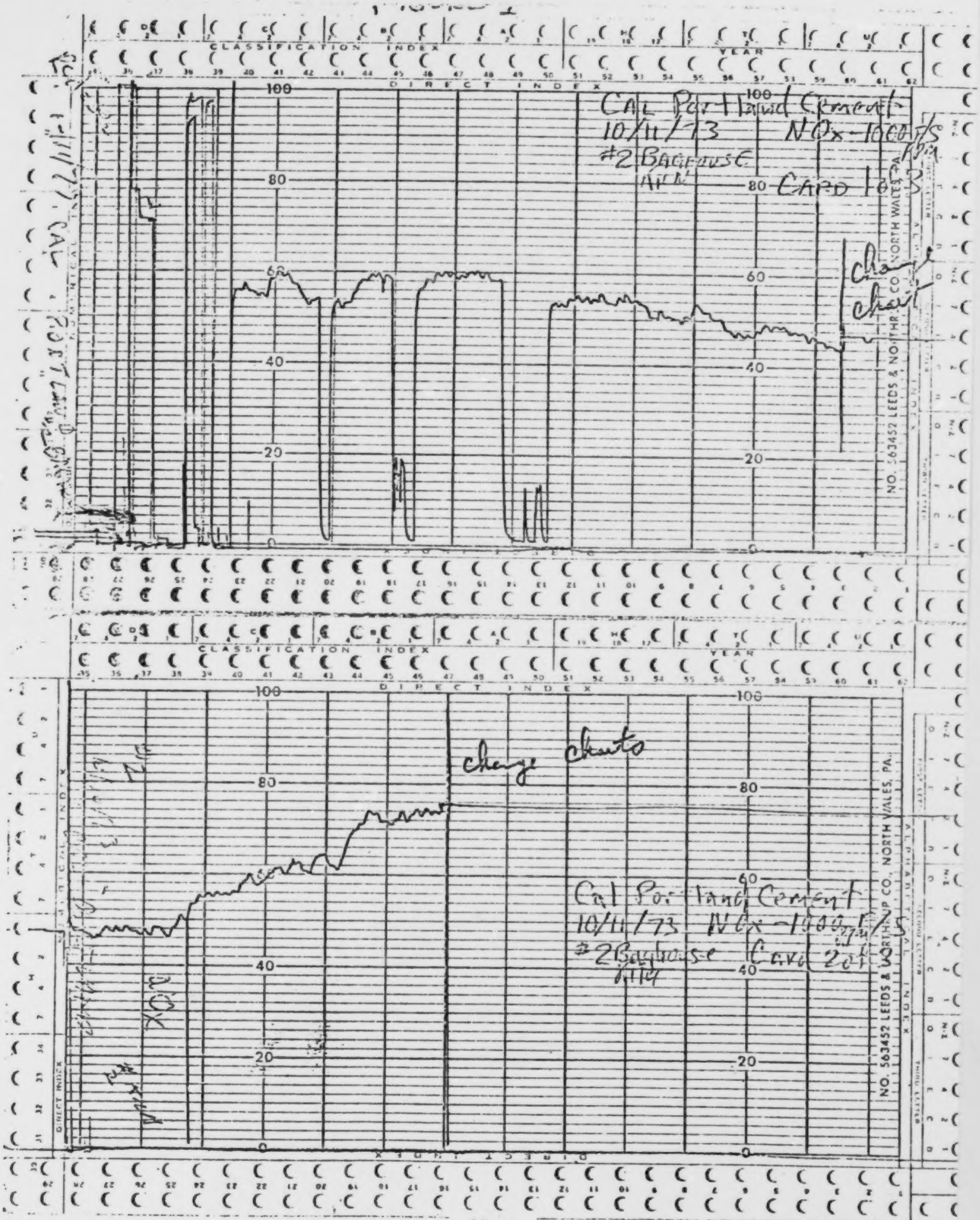

CAL Portland Cement
10/11/73 NOx-1000 ppm
#2 Baghouse
APN
Card 1 of 3
change chart
10/11/73 CAL PORTLAND CEMENT
change charts
Cal Portland Cement
10/11/73 NOx-1000 ppm
#2 Baghouse Card 2 of 3
APN
NOX
100
80
60
40
20
0
CLASSIFICATION INDEX
YEAR
DIRECT INDEX
NO. 563452 LEEDS & NORTHRUP CO. NORTH WALES, PA.

FIGURE 1
(CONT.)

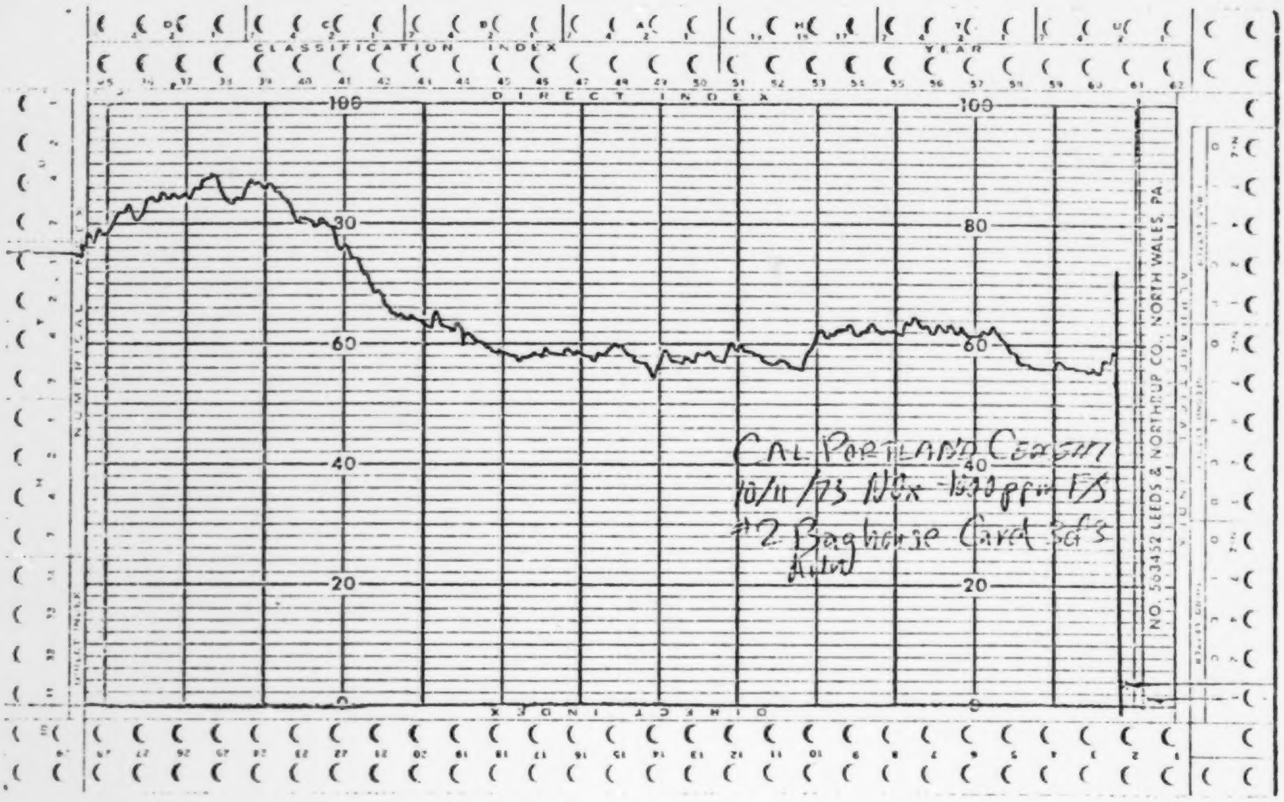
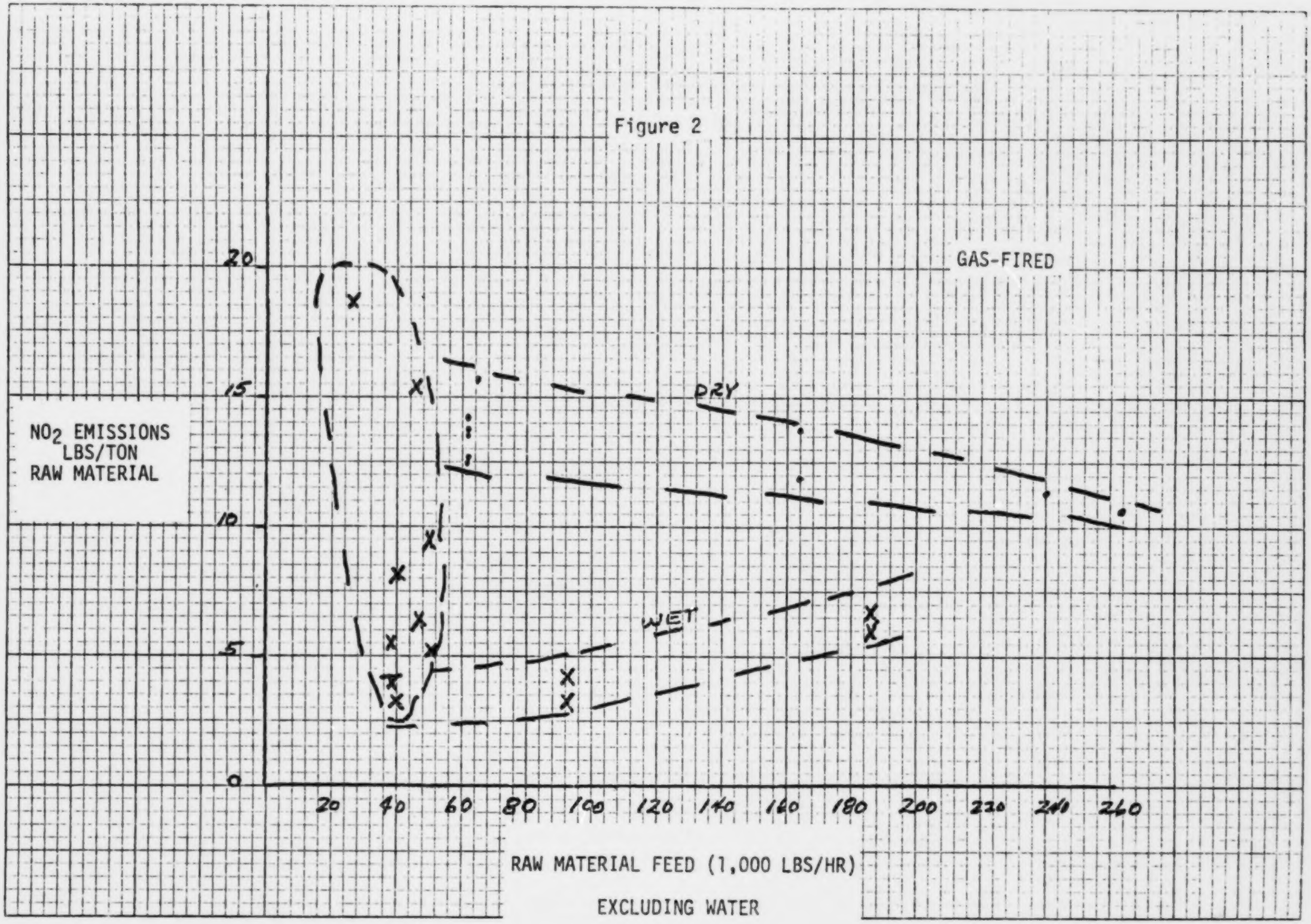


Figure 2



46 0782
K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

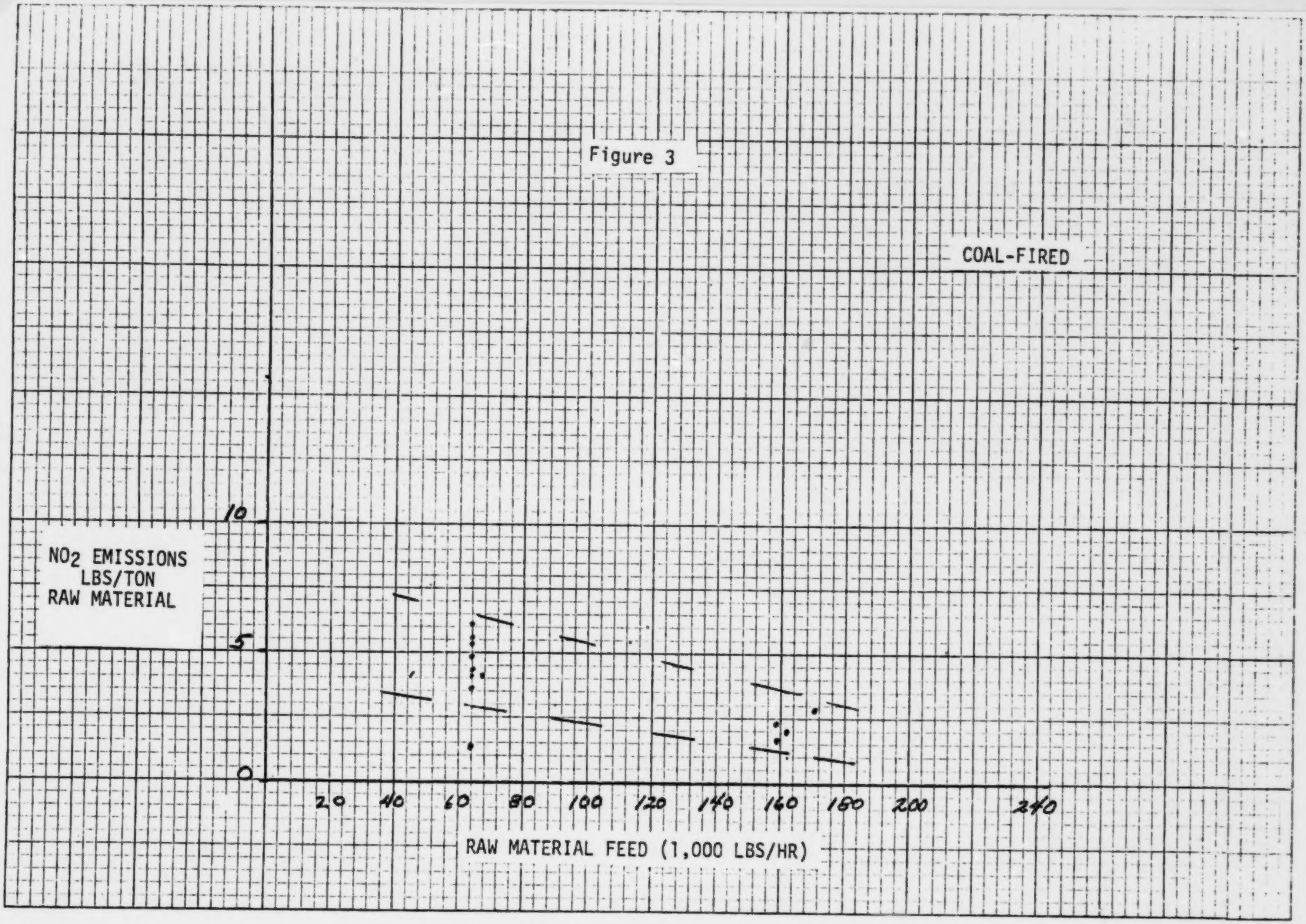
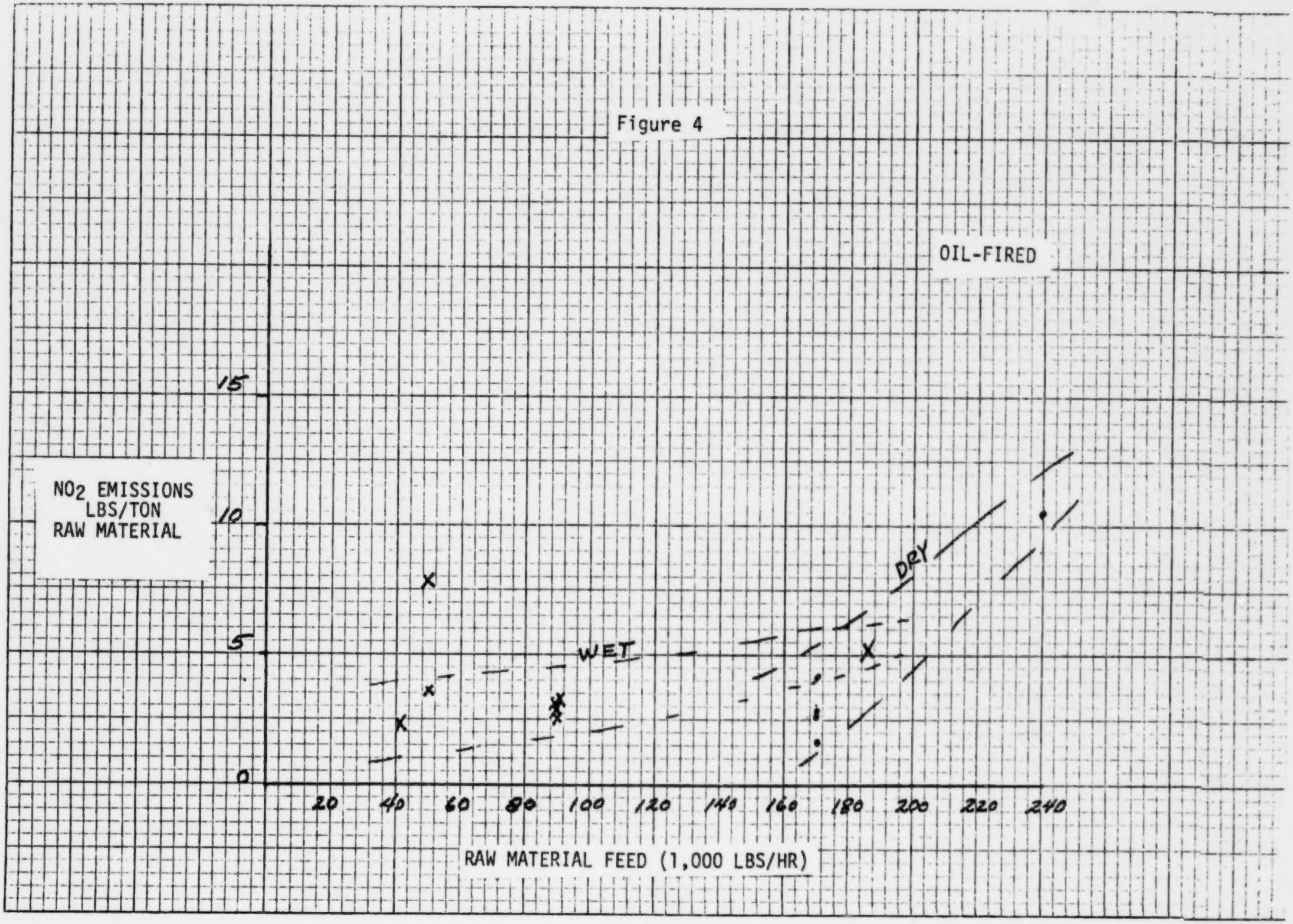


Figure 3

K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0782

Figure 4


OIL-FIRED
NO$_2$ EMISSIONS LBS/TON RAW MATERIAL
0
5
10
15
WET
DRY
20
40
60
80
100
120
140
160
180
200
220
240
RAW MATERIAL FEED (1,000 LBS/HR)

CONDENSED DISCUSSION

QUESTION: What is the difference in tests on kilns using natural gas and coal as fuel?

HILOVSKY: There is no difference in running coal versus natural gas. The dust loading from the cement process is so high that actually the ashes absorb in the cement. It actually makes a better cement product.

QUESTION: Do the production rates change when you change fuels? What are the heat release rate differences?

HILOVSKY: Let's see if I can go back to the charts. There is a slight change in the total raw materials going in. On gas they were running around 161 thousand pounds of raw material in that particular kiln. They are running 151 thousand pounds of raw material on 20 thousand pounds of coal. Approximately the same out-put. Still 15 tons per kiln.

QUESTION: When were these tests run?

HILOVSKY: All the way from '69 through two or three weeks ago. I might say that we run, or we have had a policy of testing all of our large companies at least on an annual basis and sometimes two times a year depending upon how good they have been in terms of compliance. We have more test on this one in the south coast basin because it's closer to us and we have done some research work with them. We have tested our instruments there and a few other things.

QUESTION: Do you have a significant amount of carbon monoxide fluctuation?

HILOVSKY: We have been taking samples and didn't notice any significant difference. I don't have that with my data here, but when we go out and sample, we take everything. We take carbon monoxide, SO_2, and NO_x and particulate matter all at the same time.

QUESTION: Do you have a wet process estimate?

HILOVSKY: There is no wet process on coal yet. One of the companies running a wet process has the application already approved to construct coal handling facilities. At present though, it is not in business.

CURRENT API EMISSION MEASUREMENT PROGRAMS

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

J. G. Zabaga
Associate Engineer
Mobil Research & Development Corporation
Princeton, New Jersey 08540

Introduction

My name is J. G. Zabaga. I represent the American Petroleum Institute, and specifically, the Committee on Evaporation Loss Measurement (CELM). I am the Chairman of CELM.

A great deal of current interest is being focused on the evaporation loss bulletins that have been published by the American Petroleum Institute over a period of years. Publication of the bulletins preceded the Clean Air Act Amendments of 1970, and it has now become clear that both industry and regulators need updated emissions data to properly respond to the Act.

To start, I would like to review the function of the Committee on Evaporation Loss Measurement. Figure 1 shows the organizational structure of the American Petroleum Institute (API). There are a number of technically oriented departments, one of which is Non-Departmental/Industry Affairs. Within that Department, as shown in Figure 2, is the Committee on Petroleum Measurement (COPM), a free-standing API-based committee. Titles of the standing committees describe, in general, the scope of the Committee's responsibilities, all ultimately resulting in the establishment of standards for measurements of all types of petroleum products throughout the industry. This includes production, refining, distribution and marketing activities.

The CELM is one of COPM's standing committees. CELM deals only with the measurement of evaporation loss, which is quite different from the finite measurement considerations of the other committees in developing standards for inventory control or custody transfer.

Figure 3 lists the publications of the CELM that were developed over a 12-year period from 1957-1969. These bulletins were the first industry-published data on quantifying evaporation loss of hydrocarbon liquids, and they have been widely accepted. To this day they remain, or are the basis for, virtually all data sources dealing with hydrocarbon evaporation loss. The several editions of the EPA's AP-42 Compilation of Air Pollution Control Factors, have emission factors derived from these bulletins.

It is important to realize that all of the bulletins were published prior to the U. S. Clean Air Act and do not necessarily comprehend the accuracy levels required by the Act. In fact, the bulletins were originally developed to enable oil company operating divisions to prepare cost benefit studies for evaluation of alternative conservation techniques. When the data and estimating methods became one of the tools used by regulators for control strategies, industry requested that API review the content of all of the bulletins for suitability in this new application.

Figure 4 shows the present organization of CELM, including active subcommittees. Figure 5 is a pictorial view of the equipment involved within each subcommittee's responsibility. The five subcommittees and any ad hoc task groups are staffed by 31 members, 21 from oil companies and 10 from supplier companies.

Referring to Figure 5, the petroleum liquids of concern to the Committee, and the basic equipment and handling characteristics are as follows:

1) Open top floating-roof tanks have been in use since 1880 and in their present form since 1923. The concept is to curtail evaporation by floating a disc, the movable roof, in the liquid. Under certain conditions, some emissions result from the perimeter sealing ring area. Floating-roof tanks are usually used for liquids with storage vapor pressures between about 1.5

to 11 psia i.e., motor and aviation gasolines, and some crude oils.

2) Internal floating covers or covered floating-roof tanks are a logical combination of open top and fixed-roof tanks, providing weather protection to the roof and contents, and evaporation control by use of a floating deck. Liquids generally stored are the same as open top floating-roof tanks.

3) Fixed-roof tanks have been used for many years to store all types of petroleum. Recognition by industry that product could be conserved by use of one of the floating-roof systems and later, regulations to limit use to liquids with less than 1.5 psia storage vapor pressure, have generally restricted use of fixed-roof tanks to low volatility liquids, i.e., distillates, residuals and some crude oils.

4) Tank truck and tank car considerations are confined primarily to motor gasolines. Some crude oil and other finished product are also transported by these means. The method of loading is apparently the feature most

affecting evaporation loss.

5) Marine vessels transport crude oils and all types of finished product. The depth of the loaded compartment is a major factor affecting evaporation loss as we will see later.

When evaporation loss data were developed by the original committee, the resulting bulletins were not intended for use as a means to determine emission factors for conducting emissions inventories nor for the evaluation of regulatory strategies. Their use for such purposes may be both impractical and improper. The subcommittees that developed and/or subsequently revised the bulletins recognized that the estimating methodology and data had precision appropriate only for comparative correlations among varying hardware designs and different hydrocarbon liquids. The estimating techniques in the bulletins were, for the most part, originally developed and standardized from data collected in the period 1930-1950. Within the specific purposes of allowing the industry to evaluate on a cost/benefit basis, with a limited precision, alternative vapor conservation devices, these techniques were entirely adequate. However, the techniques are not satisfactory in a regulatory climate demanding data that comprehends technical advancements in both testing methods and equipment design.

In most applications, the present bulletins have been found to overstate losses when compared to new, detailed tests. This will be amplified in the discussions that follow. I do want to emphasize now that the API Committee on Evaporation Loss Measurement, consistent with current Institute policy and direction, is charged with regularly revising its publications to incorporate technological improvements in the state of the art on vessel and hardware design, and testing methods.

Marine Terminal Emissions

In 1976, CELM updated Bulletin 2514A, Hydrocarbon Emissions from Marine Vessel Loading of Gasolines. A small but important point in the bulletin title is the use of the term emissions. API distinguishes between the terms evaporation loss and emissions. The industry has traditionally required loss data expressed as a volumetric change, i.e., barrels per year, for use in inventory control. This volume change is defined as evaporation loss. Regulators are properly interested in mass quantity of hydrocarbon released per unit of time, i.e., pounds per day; this is defined as emissions. API bulletins published subsequent to 1976 will include factors for both purposes.

Figure 6 shows a summary of emission factors from 83 tests performed by four companies loading motor gasoline into ships and barges. These factors average about 40 percent of previously published data. The chart format also suggests the parameters that were found to dominate the evaporation phenomena. Filling a container with petroleum product produces emissions by displacement of the existing vapor space. The hydrocarbon concentration in the vessel vapor space was found to consist of two distinct components: vapors that existed before loading started - the arrival vapors, and vapors generated by the loading operation. Figure 7 depicts this phenomenon. Arrival vapors in ships were found to be quite lean, averaging about two to seven percent hydrocarbon, while the average hydrocarbon content of emitted vapors for the entire loading sequence was only five to 11 percent.

The generated vapors form a rich blanket, about four to eight feet deep, that floats on the liquid level in the arrival vapors. Tankers have compartments typically 50 to 60 feet deep. Loading terminates within a few feet of the deck. Therefore, displaced vapors reflect about 45 feet of arrival vapors and two to six feet of the rich blanket.

Barge loading is similar to tanker loading except that the shallow compartment depths, about 12 feet, permit more of the rich blanket to escape. The emission profile is similar, with slightly higher hydrocarbon levels, but still lower than previously anticipated.

The concentration of arrival hydrocarbons reflects the history of each vessel compartment since the previous unloading. Low levels generally indicate that the compartment was cleaned on the return voyage, perhaps to accommodate an unleaded gasoline in a compartment that previously held leaded product, to switch to heating oil from gasoline service, or indirect cleaning by ballasting the compartment for navigational reasons. For any specific marine terminal, the percentage of compartments that arrive clean annually can be determined by analysis of ships logs and terminal records. With this information the factors in Figure 6 can be used with confidence in predicting emission levels when loading motor gasolines.

Other factors are still required for loading crude oils and for emissions resulting from water ballasting of vessels after unloading either gasoline or crude.

The Western Oil and Gas Association has just completed a test program on loading California crudes and will publish a report shortly. Preliminary test results indicate phenomena similar to gasoline loading, with emission factors generally lower than gasoline. Also, eight oil companies, acting in response to an EPA 114A letter, have started a joint program to develop new data on ballasting emissions, plus any information necessary to fill gaps in the previously described API and WOGA studies. Correlation of all of these efforts should provide the data base necessary for publication of new, comprehensive marine terminal emission factors by mid-1978.

Floating-Roof Tanks

Emissions from floating-roof tanks have been under intensive investigation since last summer. While much of the data in the original API Bulletin (2517) was about 40 years old, the relatively slow evaporation rate from floating-roof tank seals and the difficulty in measuring the evaporation loss have generally frustrated any new in-depth studies.

Figure 8 depicts a floating-roof tank and the perimeter seal area through which losses occur. The amount of evaporation occurring in a reasonable amount of time, say several months with the tank dormant, is too small to detect reliably with conventional measuring techniques.

Two methods have been used within the last year in an attempt to overcome this problem. As shown in the figure, a field tank with product in it is taken out of active service and permitted to weather. Separate testing has established that any evaporation due to tank wall wetting as the roof descends in normal operations is insignificant. Therefore, any emissions are those that result from loss of lighter gasoline components through the seal area. Further, tests have also shown that natural convective mixing maintains a homogeneous liquid in the tank. This establishes the format for one test approach. Periodic samples are taken and the density of the bulk liquid remaining is determined with an extremely precise densitometer. Sensitivity is required, in grams per millilitre, to five decimal places. Establishing a time rate of density increase (increase due to loss of the lighter components) permits calculation of decrease in bulk volume.

A test program, using the density change method and involving 13 gasoline tanks, was completed in January by the Western Oil and Gas Association. Average evaporation loss was about half of previously published values.

A second test program, also completed recently, was conducted by Chicago Bridge and Iron Company and Standard Oil of Ohio. Here a 20 foot covered pilot tank, designed to simulate climatic and product variables, was used to capture and account for all hydrocarbon losses. This was a unique and pioneering effort. Being capable of isolating individual variables, the study program developed a clearer understanding of the significance of the parameters affecting evaporation. Wind in particular was determined to play a dominant role in the evaporation process. The test program was designed for a specific client's application, and within that framework - the latest in tank and seal technology for storage of crude oil - indicates emission levels at about 10 to 20 percent of previously published values.

These programs cannot be extrapolated to a data base adequate to provide a comprehensive emission predicting method for all types of floating-roof tanks in all geographical and service conditions. CELM has started a program to complement, correlate and conclude the two efforts just described and to develop new bulletins 2517, Evaporation Loss from Floating-Roof Tanks, and 2519, Use of Internal Floating Covers and Covered Floating Roofs to Reduce Evaporation Loss, applicable to any open top or covered floating-roof tank. That work is scheduled for completion by early 1979.

Fixed-Roof Tanks

Current correlations for fixed-roof tanks are confined to products with a vapor pressure greater than two psia, and due to a limited data base, to tanks with diameters less than about 150 feet. Therefore, some crude oils, residuals and distillates stored in larger modern tanks are excluded. It is desireable to establish emission levels for these products. The Western Oil and Gas Association has just completed a 46-tank test program on crude and distillate liquids that provide some new data on emission levels. The study demonstrates the apparent significance of the way a tank is operated, e.g., continuous in-out flow, fast filling and slow emptying, etc., and the importance of vapor pressure on loss, and generalizes that emission levels are about half of API 2518 estimates. This agrees roughly with work done last year in Germany indicating that filling losses are 88 percent and breathing losses 11 percent of API 2518 estimates. However, no new emission formulae were developed by either program.

Two API committees, including CELM, are advancing a joint program, building on these recent studies, to produce a new comprehensive prediction method applicable to all service conditions. A revised Bulletin 2518, Evaporation Loss from Fixed-roof Tanks, is planned for publication in 1978.

Truck and Tank Car Emissions

Emissions from these mobile sources are the final area of CELM's immediate concern. Advancements in loading methods, e.g., bottom filling vs. submerged fill pipes or splash loading, and the effect of vapor recovery units must be evaluated. The effects of Stage 1 service station return vapors will also affect evaporation loss. Much information on these items has already been collected by industry and regulators. Emission levels calculated by Bulletin 2514 again appear to be overstated, particularly for the increasingly popular bottom loading. Bottom loading was not common when Bulletin 2514 was published in 1959. The industry has traditionally used correlations for the apparently similar submerged loading which have been found to produce emission estimates about one-third higher than the current testing of bottom loading systems indicates.

CELM is analyzing the latest test data to verify its adequacy for new vehicle loading correlations. Any additional testing required to ensure a comprehensive data base should be completed this year. A totally re-written Bulletin 2514B is scheduled for publication in early 1978.

Summary

The CELM organization chart in Figure 9 shows the major areas of evaporation loss activity of immediate concern to regulators and industry.

The existing evaporation loss bulletins, originally prepared for economic comparisons, have been shown to generally overstate emissions, restricting their proper use to industry and for control strategies. All of the pertinent bulletins are in some stage of updating, with publication schedules being expedited to make the new information available as soon as possible. These programs are expensive and extensive. Total cost of testing will approach $2 million. During the data accumulation period, cooperation by industry and government will be required to ensure a comprehensive data bank satisfactory to each.

American Petroleum Institute
STAFF ORGANIZATION

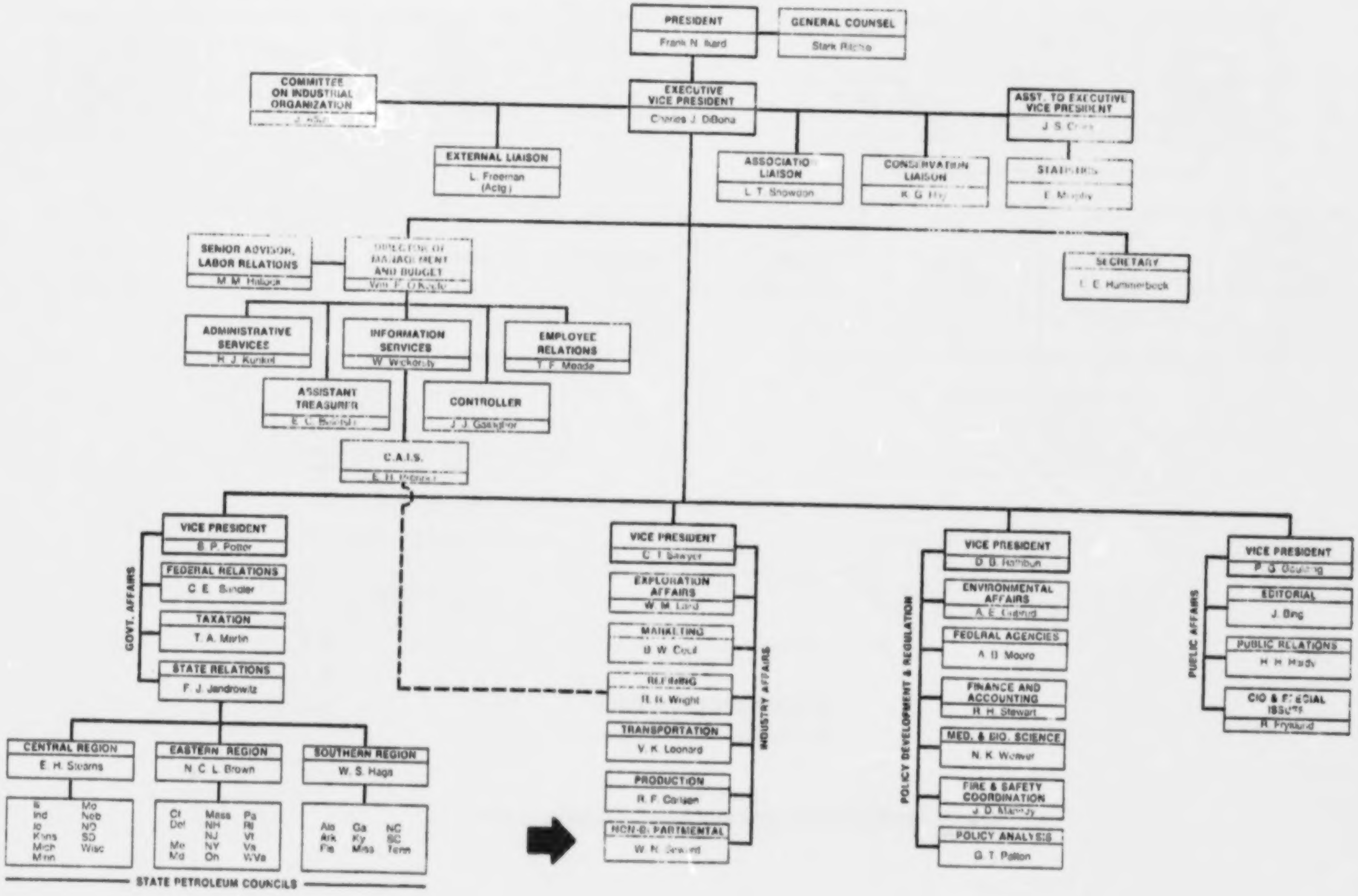

PRESIDENT
Frank N. Ikard
GENERAL COUNSEL
Stark Ritchie
COMMITTEE ON INDUSTRIAL ORGANIZATION
EXECUTIVE VICE PRESIDENT
Charles J. DiBona
ASST. TO EXECUTIVE VICE PRESIDENT
J. S. Cross
EXTERNAL LIAISON
L. Freeman (Actg.)
ASSOCIATION LIAISON
L. T. Snowdon
CONSERVATION LIAISON
K. G. Hay
STATISTICS
E. Murphy
SENIOR ADVISOR, LABOR RELATIONS
M. M. Hallock
DIRECTOR OF MANAGEMENT AND BUDGET
Wm. F. O'Keefe
SECRETARY
E. E. Hammerbeck
ADMINISTRATIVE SERVICES
H. J. Kunkel
INFORMATION SERVICES
W. Wickersty
EMPLOYEE RELATIONS
T. F. Meade
ASSISTANT TREASURER
E. C. Bassler
CONTROLLER
J. J. Gallagher
C.A.I.S.
VICE PRESIDENT
B. P. Potter
FEDERAL RELATIONS
C. E. Sindler
TAXATION
T. A. Martin
STATE RELATIONS
F. J. Jandrowitz
GOVT. AFFAIRS
CENTRAL REGION
E. H. Stearns
Ill
Ind
Io
Kans
Mich
Minn
Mo
Neb
ND
SD
Wisc
EASTERN REGION
N. C. L. Brown
Ct
Del
Me
Md
Mass
NH
NJ
NY
Oh
Pa
RI
Vt
Va
WVa
SOUTHERN REGION
W. S. Haga
Ala
Ark
Fla
Ga
Ky
Miss
NC
SC
Tenn
STATE PETROLEUM COUNCILS
VICE PRESIDENT
C. T. Sawyer
EXPLORATION AFFAIRS
W. M. Lord
MARKETING
B. W. Cook
REFINING
R. H. Wright
TRANSPORTATION
V. K. Leonard
PRODUCTION
R. F. Carlson
NON-DEPARTMENTAL
W. N. Seward
INDUSTRY AFFAIRS
VICE PRESIDENT
D. B. Rathbun
ENVIRONMENTAL AFFAIRS
A. E. Cuenod
FEDERAL AGENCIES
A. B. Moore
FINANCE AND ACCOUNTING
R. H. Stewart
MED. & BIO. SCIENCE
N. K. Weaver
FIRE & SAFETY COORDINATION
J. D. Mahaffey
POLICY ANALYSIS
G. T. Patton
POLICY DEVELOPMENT & REGULATION
VICE PRESIDENT
P. G. Goulding
EDITORIAL
J. Bing
PUBLIC RELATIONS
H. H. Hardy
CIO & SPECIAL ISSUES
R. Frydlund
PUBLIC AFFAIRS
SEPT 1977

Figure 1

API COMMITTEE ON PETROLEUM MEASUREMENT

MAY 31, 1977

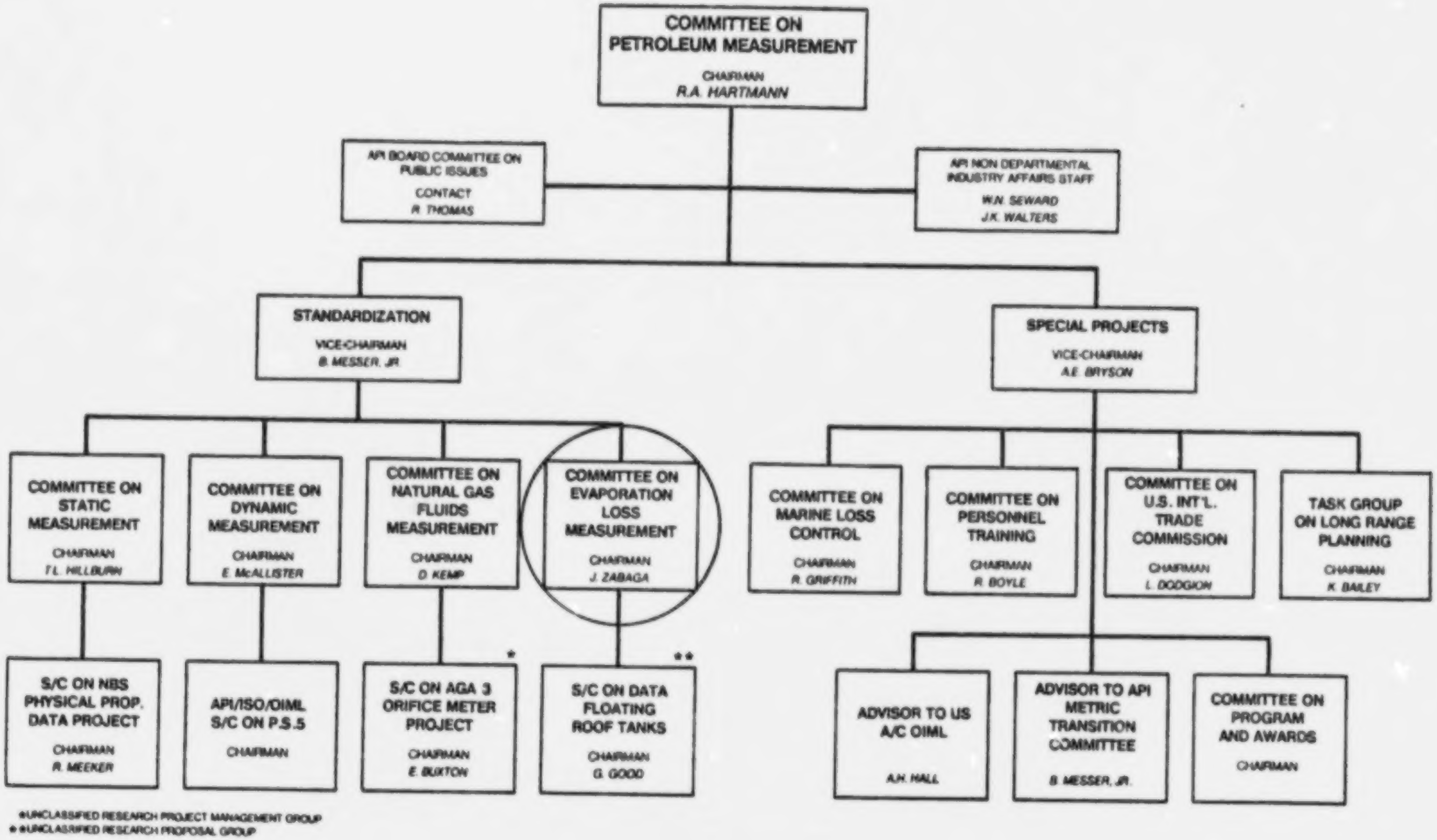

COMMITTEE ON PETROLEUM MEASUREMENT
CHAIRMAN
R.A. HARTMANN
API BOARD COMMITTEE ON PUBLIC ISSUES
CONTACT
R. THOMAS
API NON DEPARTMENTAL INDUSTRY AFFAIRS STAFF
W.N. SEWARD
J.K. WALTERS
STANDARDIZATION
VICE-CHAIRMAN
B. MESSER, JR.
SPECIAL PROJECTS
VICE-CHAIRMAN
A.E. BRYSON
COMMITTEE ON STATIC MEASUREMENT
CHAIRMAN
T.L. HILLBURN
COMMITTEE ON DYNAMIC MEASUREMENT
CHAIRMAN
E. McALLISTER
COMMITTEE ON NATURAL GAS FLUIDS MEASUREMENT
CHAIRMAN
D. KEMP
COMMITTEE ON EVAPORATION LOSS MEASUREMENT
CHAIRMAN
J. ZABAGA
COMMITTEE ON MARINE LOSS CONTROL
CHAIRMAN
R. GRIFFITH
COMMITTEE ON PERSONNEL TRAINING
CHAIRMAN
R. BOYLE
COMMITTEE ON U.S. INT'L. TRADE COMMISSION
CHAIRMAN
L. DODGION
TASK GROUP ON LONG RANGE PLANNING
CHAIRMAN
K. BAILEY
S/C ON NBS PHYSICAL PROP. DATA PROJECT
CHAIRMAN
R. MEEKER
API/ISO/OIML S/C ON P.S.5
CHAIRMAN
S/C ON AGA 3 ORIFICE METER PROJECT *
CHAIRMAN
E. BUXTON
S/C ON DATA FLOATING ROOF TANKS **
CHAIRMAN
G. GOOD
ADVISOR TO US A/C OIML
A.H. HALL
ADVISOR TO API METRIC TRANSITION COMMITTEE
B. MESSER, JR.
COMMITTEE ON PROGRAM AND AWARDS
CHAIRMAN
*UNCLASSIFIED RESEARCH PROJECT MANAGEMENT GROUP
**UNCLASSIFIED RESEARCH PROPOSAL GROUP

Figure 2

API EVAPORATION LOSS BULLETINS

API BULLETIN 2512: TENTATIVE METHODS OF MEASURING EVAPORATION LOSS FROM PETROLEUM TANKS AND TRANSPORTATION EQUIPMENT (1957)

API BULLETIN 2513: EVAPORATION LOSS IN THE PETROLEUM INDUSTRY—CAUSES AND CONTROL (1959)

API BULLETIN 2514: EVAPORATION LOSS FROM TANK CARS, TANK TRUCKS, AND MARINE VESSELS (1959)

API BULLETIN 2515: USE OF PLASTIC FOAM TO REDUCE EVAPORATION LOSS (1961)

API BULLETIN 2516: EVAPORATION LOSS FROM LOW-PRESSURE TANKS (1962)

API BULLETIN 2517: EVAPORATION LOSS FROM FLOATING-ROOF TANKS (1962)

API BULLETIN 2518: EVAPORATION LOSS FROM FIXED-ROOF TANKS (1962)

API BULLETIN 2519: USE OF INTERNAL FLOATING COVERS FOR FIXED-ROOF TANKS TO REDUCE EVAPORATION LOSS (1962)

API BULLETIN 2520: USE OF VARIABLE-VAPOR-SPACE SYSTEMS TO REDUCE EVAPORATION LOSS (1964)

API BULLETIN 2521: USE OF PRESSURE-VACUUM VENT VALVES FOR ATMOSPHERIC PRESSURE TANKS TO REDUCE EVAPORATION LOSS (1966)

API BULLETIN 2522: COMPARATIVE METHODS FOR EVALUATING CONSERVATION MECHANISMS FOR EVAPORATION LOSS (1967)

API BULLETIN 2523: PETROCHEMICAL EVAPORATION LOSS FROM STORAGE TANKS (1969)

Figure 3

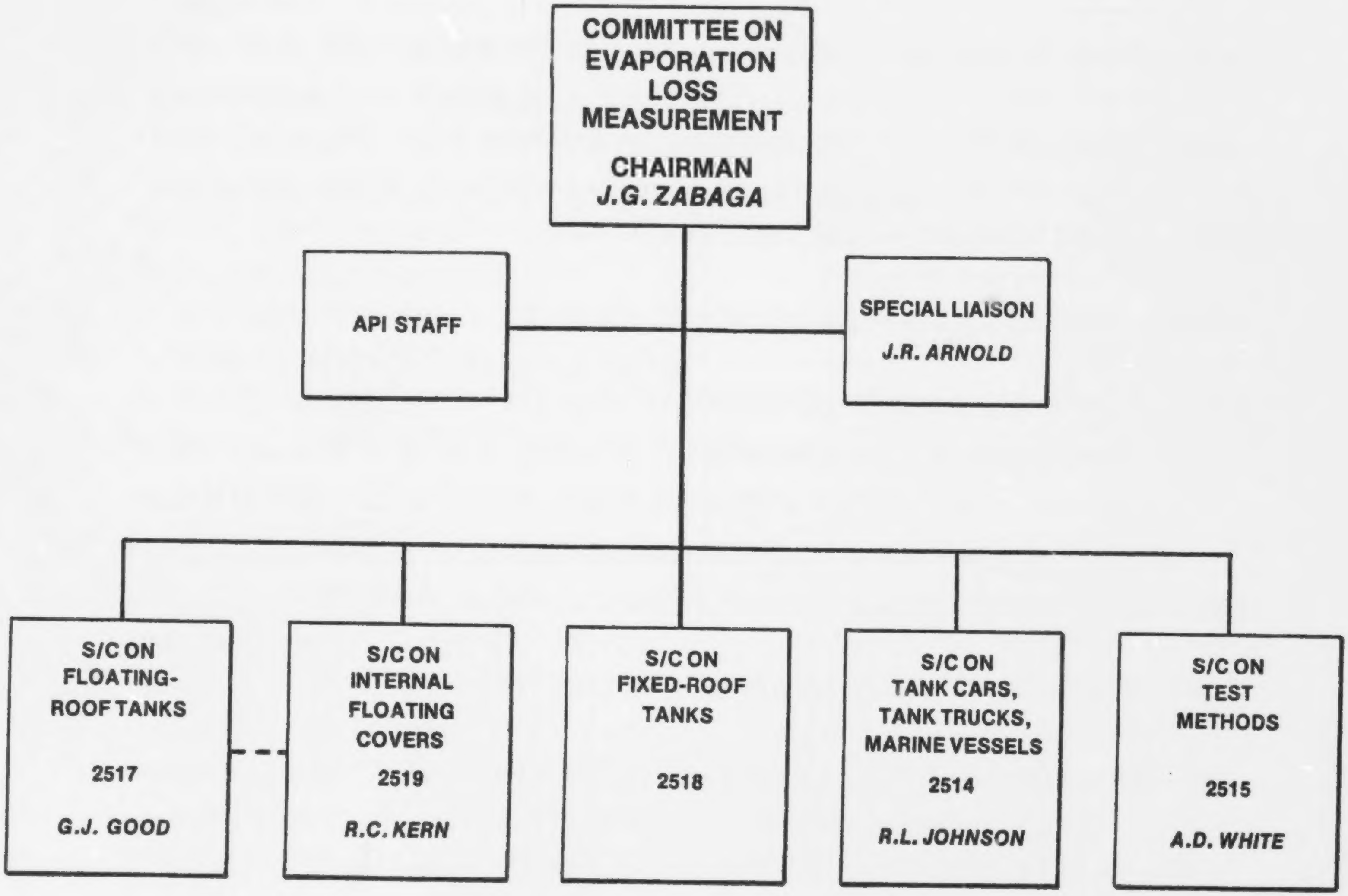

COMMITTEE ON EVAPORATION LOSS MEASUREMENT
CHAIRMAN J.G. ZABAGA
API STAFF
SPECIAL LIAISON J.R. ARNOLD
S/C ON FLOATING-ROOF TANKS 2517 G.J. GOOD
S/C ON INTERNAL FLOATING COVERS 2519 R.C. KERN
S/C ON FIXED-ROOF TANKS 2518
S/C ON TANK CARS, TANK TRUCKS, MARINE VESSELS 2514 R.L. JOHNSON
S/C ON TEST METHODS 2515 A.D. WHITE

Figure 4

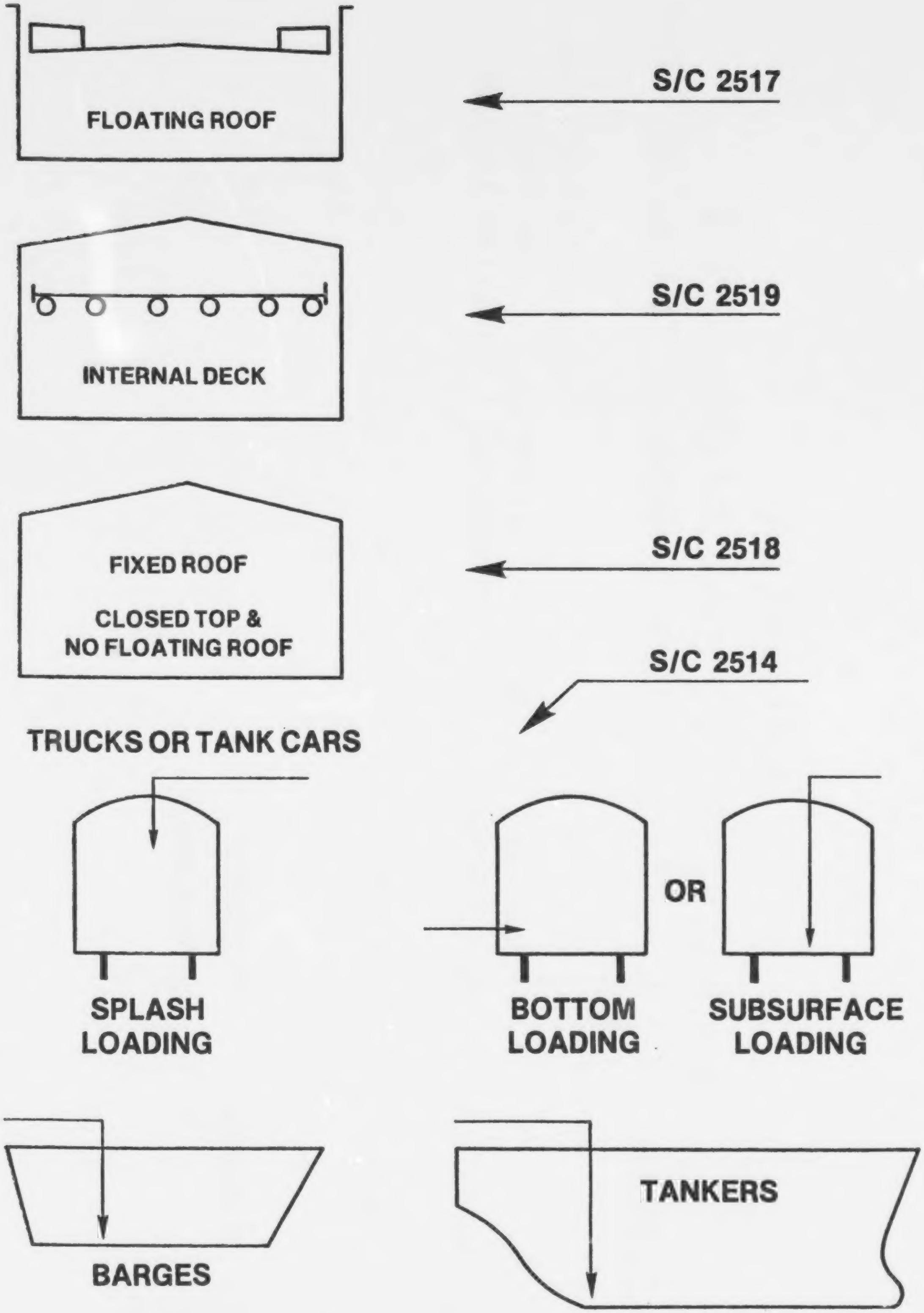

FLOATING ROOF
S/C 2517
INTERNAL DECK
S/C 2519
FIXED ROOF
CLOSED TOP &
NO FLOATING ROOF
S/C 2518
S/C 2514
TRUCKS OR TANK CARS
OR
SPLASH
LOADING
BOTTOM
LOADING
SUBSURFACE
LOADING
BARGES
TANKERS

Figure 5

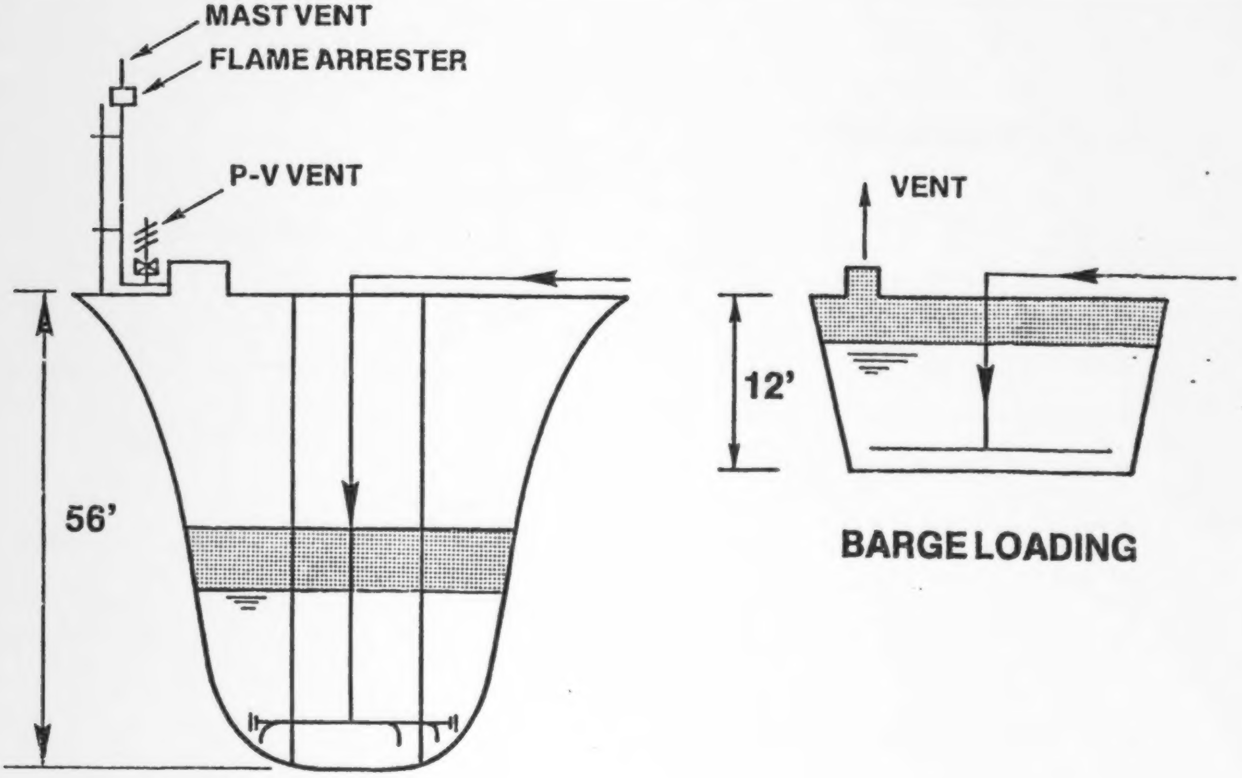
API 2514A

MARINE VESSEL LOADING OF GASOLINES

SUMMARY OF AVERAGE HYDROCARBON EMISSION FACTORS

VESSELS	ARRIVAL CONDITIONS	NO. OF COMPARTMENTS TESTED	EMISSION FACTORS (lbs./1000 GALLONS LOADED)
SHIPS	CLEANED	50	1.3
	UNCLEANED	21	2.5
BARGES	CLEANED	1	1.2
	UNCLEANED	11	3.8

Figure 6



MAST VENT
FLAME ARRESTER
P-V VENT
56'
VENT
12'

SHIP LOADING

BARGE LOADING

TYPICAL SHIP LOADING EMISSION PROFILE

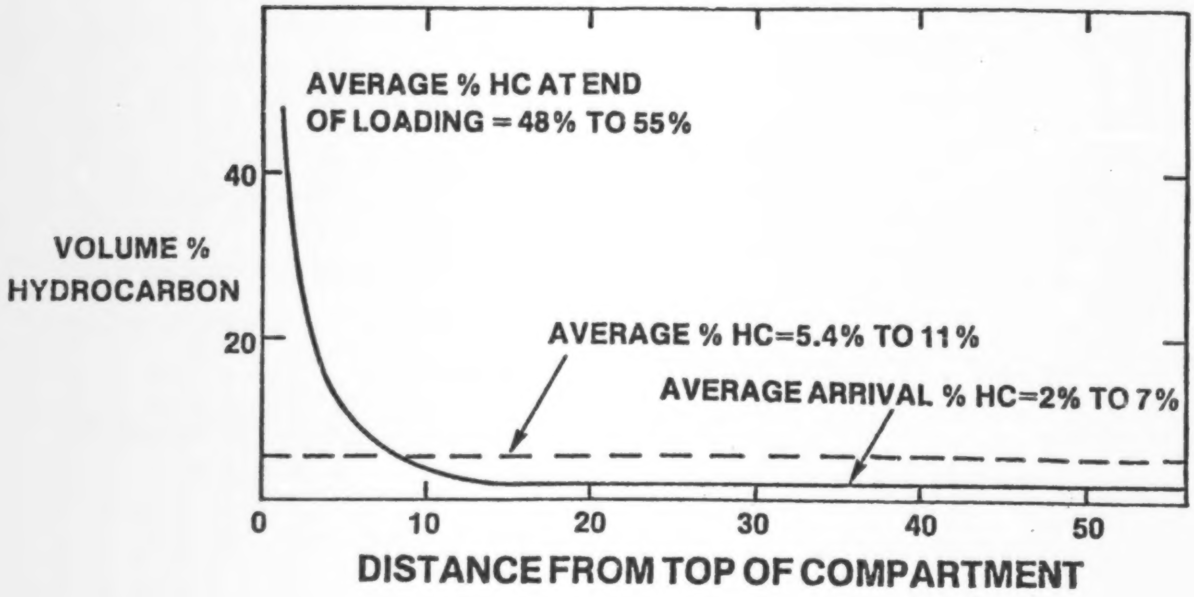
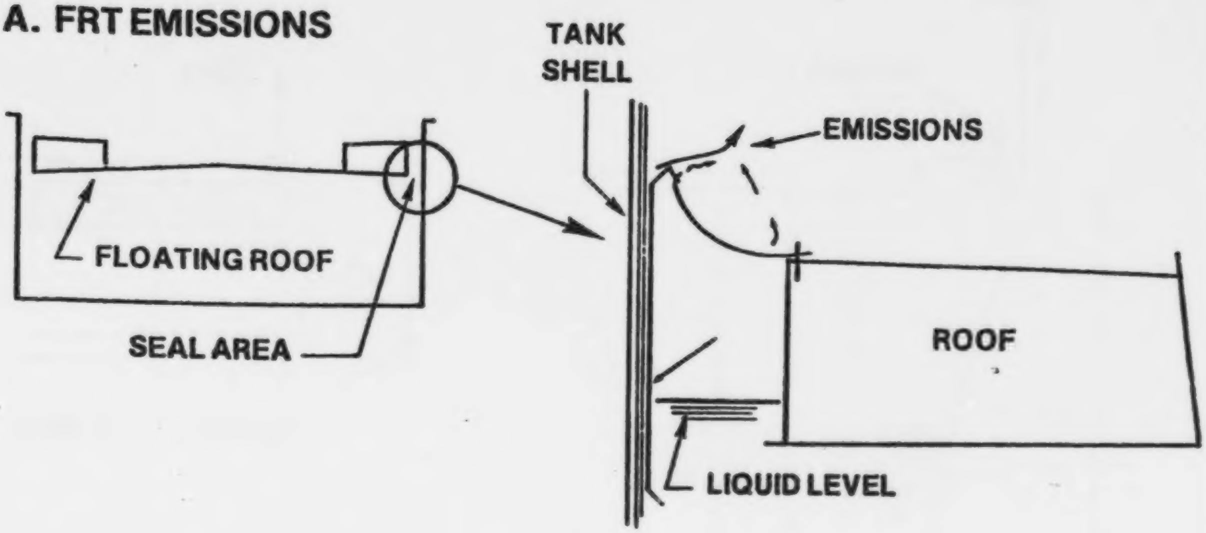


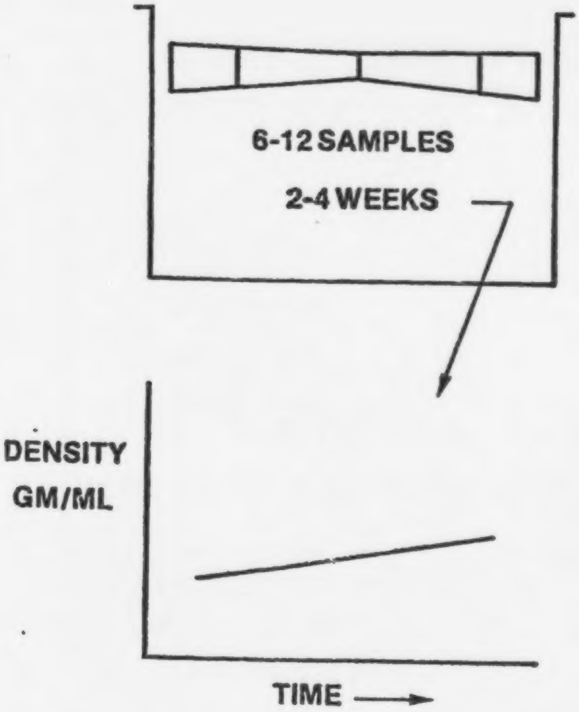
Figure 7

A. FRT EMISSIONS

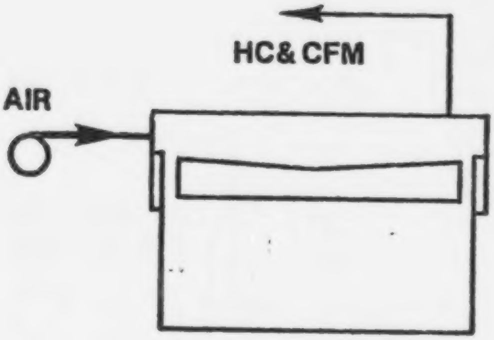

TANK SHELL
EMISSIONS
FLOATING ROOF
SEAL AREA
ROOF
LIQUID LEVEL

B. TESTING METHODS

1. DENSITY CHANGE
DORMANT FIELD TANKS


6-12 SAMPLES
2-4 WEEKS
DENSITY
GM/ML
TIME ⟶

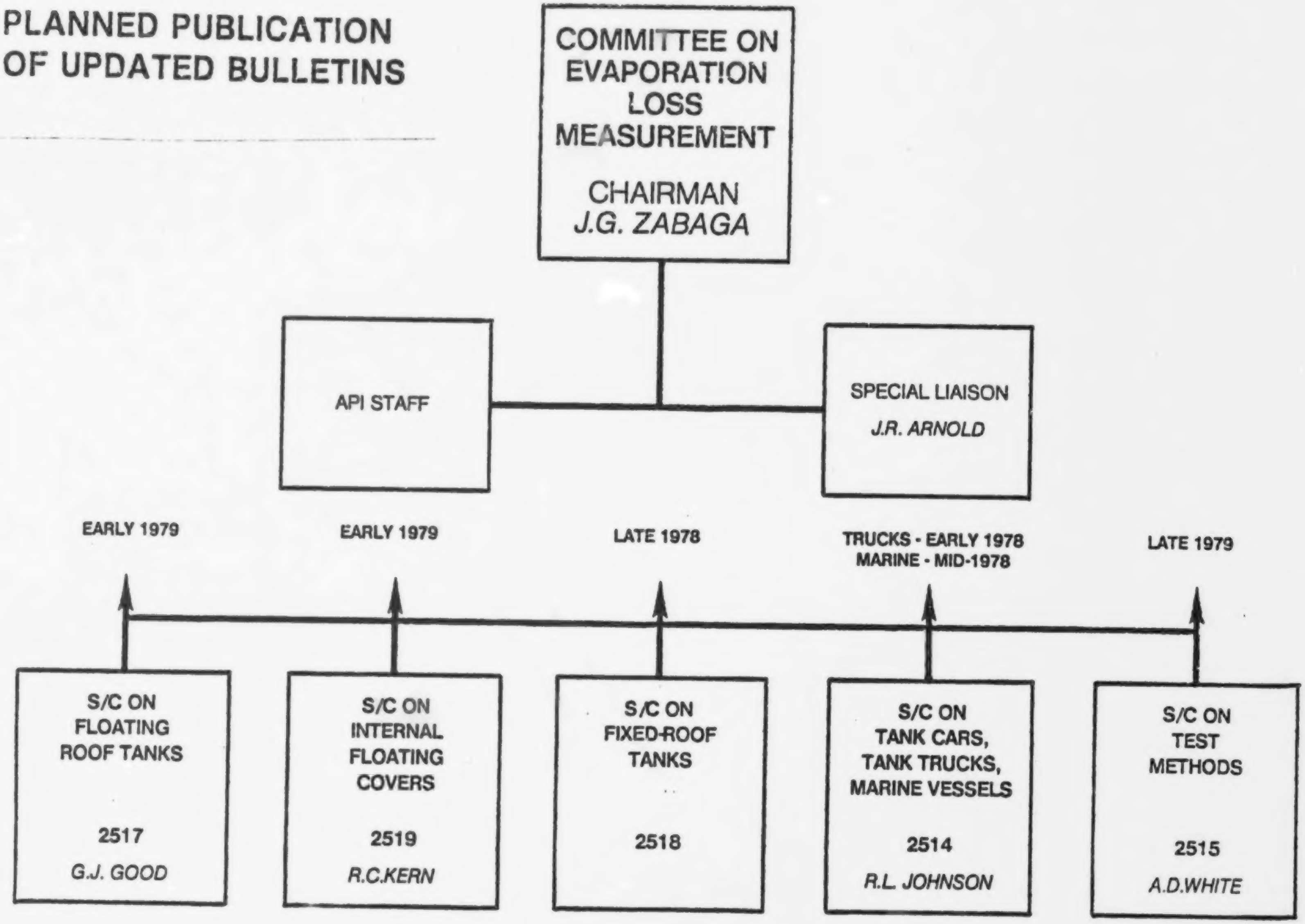
2. PILOT TANK



- VARY PRODUCT, TEMPERATURE, PRESSURE, WIND EFFECT & SEAL CONDITIONS
- COLLECT & ANALYZE EMISSIONS

Figure 8

PLANNED PUBLICATION OF UPDATED BULLETINS



COMMITTEE ON EVAPORATION LOSS MEASUREMENT

CHAIRMAN
J.G. ZABAGA

API STAFF

SPECIAL LIAISON
J.R. ARNOLD

EARLY 1979

S/C ON FLOATING ROOF TANKS
2517
G.J. GOOD

EARLY 1979

S/C ON INTERNAL FLOATING COVERS
2519
R.C.KERN

LATE 1978

S/C ON FIXED-ROOF TANKS
2518

TRUCKS - EARLY 1978
MARINE - MID-1978

S/C ON TANK CARS, TANK TRUCKS, MARINE VESSELS
2514
R.L. JOHNSON

LATE 1979

S/C ON TEST METHODS
2515
A.D.WHITE

Figure 9

HYDROCARBON EMISSIONS FROM FLOATING ROOF STORAGE TANKS

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

Dr. Robert L. Russell
Research Chemist, Union Oil Research and
Chairman of Western Oil and Gas
Association Floating Roof Tank Task Force
P. O. Box 76
Brea, California 92621

Summary

The Western Oil and Gas Association has funded several projects designed to quantify the hydrocarbon emission rate from floating-roof tanks in which volatile petroleum products are stored. These projects have involved measurements of emissions from petroleum product storage tanks in Southern and Northern California, and from a pilot scale test tank in Illinois where the environmental factors are controllable. Several important conclusions were drawn from these studies:

(1) Emissions from in-service floating-roof tanks are lower than predicted by the American Petroleum Institute Bulletin 2517 equation.

(2) Wind is the major driving force causing emissions from floating-roof tanks.

(3) Good metallic shoe seals control emissions better than good toroidal seals which do not contact the stored liquid surface.

(4) Gaps between a toroidal seal and the tank shell can substantially increase the emission rate.

(5) Gaps between a shoe seal and the tank shell result in an appreciably increased emission rate only when the gaps extend continuously over about 50% or more of the tanks circumference.

(6) The inherently low emissions from floating-roof tanks can be further reduced by placing secondary seals above the primary seals.

(7) Secondary seals reduce emissions effectively even when gaps are present in both primary and secondary seals.

(8) With reasonably well fitting secondary seals extending from the roof to the tank shell one can expect about the same emission rate for equivalent tanks of either welded or riveted construction.

History of Floating-Roof Tank Seal Controversy in Southern California

The Los Angeles County Air Pollution Control District had a rule for many years which required that floating-roof tanks storing a petroleum distillate with a vapor pressure greater than 1.5 psia must have a seal which "closes the space" between the floating roof and the tank shell. Early in 1976 California Air Resources Board (CARB) Personnel inspected floating roof petroleum storage tanks at a Southern California refinery. As a result of these inspections, CARB alleged that these tanks were causing "massive violations" of air pollution control laws and that the district's rule and enforcement procedures were not adequate to deal with the situation.

The latter allegation was based on CARB's interpretation of the phrase "closes the space". CARB interpreted this phrase to mean that there should be no gap between the seal and the tank shell, while the district had traditionally interpreted it to mean that a reasonably well functioning seal was present. Following a public hearing CARB ruled that the enforcement procedures were inadequate and consequently assumed joint enforcement authority with the district.

The allegation of excessive emissions was based on a CARB calculation which purported to show floating-roof tank hydrocarbon emissions from this one particular refinery to be 3000 tons per year. This number was obtained by using an American Petroleum Institute (API) equation for floating-roof tank evaporation loss(1) and arbitrarily increasing the calculated amount of emissions obtained for tanks with "poor" seals by up to four-fold.

Both CARB and the Southern California Air Pollution Control District (SCAPCD) conducted public hearings which involved the District's "Storage of Organic Liquids" rule (Rule 463). By mid-1976 CARB decided that gaps between a floating-roof seal and the tank shell anywhere along the circumference could not be greater than 1/8" in width. However CARB delayed enforcement of this extremely stringent gap criterion (referred to as a "no-gap" criterion) until February 1, 1977. The delay was allowed because of testimony that the Western Oil and Gas Association (WOGA) was initiating an experimental study of hydrocarbon emissions from floating-roof tanks. CARB indicated that Rule 463 might be changed if the study demonstrated that the CARB staff calculations were erroneous. If the study indicated that the CARB calculations were reasonably accurate, then all floating-roof tanks would have to immediately comply with the extremely strict gap criteria.

During the course of the WOGA studies CARB and other environmental agencies personnel were invited to regular monthly status report meetings. These meetings provided for a free and open discussion by all interested parties. All suggestions received at these meetings were carefully reviewed and incorporated within the program if they were reasonable and achievable within the time and cost constraints. This free exchange of information proved to be very beneficial in ensuring that all important factors were considered and tested during the study.

As soon as each of the project final reports was completed it was made available to CARB and all interested parties. The openness with which these studies were conducted contributed to their credibility with CARB and other environmental agency personnel. CARB subsequently used some of the conclusions, but in the opinion of WOGA personnel they did not use all of the pertinent conclusions, in their justification of recommended modifications to Rule 463.

The data from the WOGA study revealed that the original CARB calculations were erroneous. However, the study also revealed that a secondary seal could reduce the already low emissions. Therefore CARB decided to relax the gap criteria slightly and to require installation of secondary seals on all floating-roof tanks. WOGA and petroleum company representatives noted that the new CARB gap criteria were still not justified by the available data. CARB subsequently proposed gap criteria equivalent to the gaps tested in a pilot scale test tank and made it clear that any further relaxation of the gap criteria would require more data from the pilot scale test tank. Although WOGA was convinced that the data base was broad enough to justify larger gaps than had been tested, they contracted for additional tests to unequivocally prove this.

The WOGA Studies

Industry personnel generally agreed that the API Bulletin 2517 equation overestimated floating-roof tank emissions for modern floating-roof tanks. This belief was based on the following facts: (1) the equation is based on data obtained by many different companies between the 1920's and the 1950's, and (2) the data were obtained to demonstrate the superiority of floating-roof versus fixed-roof storage rather than to quantify emission levels. WOGA decided that obtaining new, hard data was the only way to ensure adoption of a rational rule.

WOGA appointed a Task Force and established three objectives: (1) to determine hydrocarbon emissions from floating-roof tanks as a function of seal gap size, vapor pressure, wind velocity and other important variables; (2) to determine what constitutes best available seal technology and to estimate hydrocarbon emissions from use of that technology; and (3) to compare hydrocarbon emissions from existing floating-roof tanks with estimated hydrocarbon emissions from the use of best available seal technology.

Part (1) of the objective was further subdivided into three tasks: field test of actual floating-roof tanks, pilot-scale testing, and laboratory testing. Standard Oil of Ohio (SOHIO) generously made available data gathered in a pilot-scale study performed for it by the Chicago Bridge and Iron Company (CBI).(2) That study involved measuring emissions from a model floating-roof tank, equipped with a toroidal primary seal, under controlled conditions. WOGA subsequently contracted with CBI to investigate the level of emissions in the model floating-roof tank when equipped with a shoe primary seal.

Field Testing of Floating-Roof Tanks

The WOGA Task Force decided that the density change method described in API Bulletin 2512(3) would be used for the field test work. Engineering Science, Inc. (ES) from Arcadia, California was selected to perform the study. CARB, Environmental Protection Agency, SCAPCD, and the San Diego APCD accepted WOGA's invitation to fully participate in the study.

The density change method relies on the fact that lighter ends evaporate faster than heavier ends from a hydrocarbon mixture. Therefore in a storage tank, with no liquid flow in or out, the weathering process increases the stored liquid's density. By use of a density-evaporation curve and with knowledge of the initial and final density and the volume of stored liquid the evaporation losses can be determined. It proved to be necessary to use a highly precise Mettler-Parr density comparator to measure densities to five decimal places.(4)

Because of the expected low emission levels it was necessary to float a 3 to 5 foot layer of hydrocarbon on water to ensure that the density change over the expected three to four month storage could be observed. Extensive laboratory testing demonstrated that the water had no significant influence on the hydrocarbon density during the storage period.(4)

In general, samples were taken via water displacement into narrow neck 8-ounce bottles at 12 different roof leg support sleeves. The 12 sampling positions were selected to represent approximately 12 equal volume elements within a tank. The data demonstrated that vertical and horizontal stratification, if it does occur, is so slight that it does not affect calculation of the average stock density.

Tanks in the field study represented a variety of different seals, products, roof heights, gaps, and tank wall types. Typical seal designs represented in the field study are shown in Figures I and II.

The average observed hydrocarbon emission rate from 13 of the study tanks is compared in Figure III to the API 2517 calculated emission rate. It can be seen that the observed emissions are approximately 1/2 of the calculated emissions instead of the 2 to 4 times greater that the CARB staff originally estimated.

Pilot Scale Testing of Floating-Roof Tank Emissions

Chicago Bridge & Iron Company (CBI) built an insulated, temperature-controllable, 20 foot diameter, 9 foot high tank with a double deck floating-roof and a cone roof cover.(2a) The tank is designed to permit blowing air through the space between the floating and cone roof. A flame ionization detector is used to determine the hydrocarbon concentration in the outlet and inlet air. The difference between these two numbers is a direct emission measurement at the preset operating conditions.

The SOHIO/CBI experiments(2) demonstrated that wind speed had a pronounced effect on emissions from a floating-roof tank equipped with a toroidal type seal. As Figure IV shows, subsequent WOGA/CBI experiments(5) demonstrated that while emissions from a floating-roof tank equipped with a shoe seal are wind speed dependent, the effect is much less pronounced than with a toroidal seal.

The SOHIO/CBI and WOGA/CBI data also demonstrated the effect of introducing gaps between the seals and the tank shell, and the effect of placing a secondary seal from the roof to the shell above the primary seal. (Typical examples of secondary seals are shown in Figure V.) Figure VI shows a data summary depicting the effect that various size gaps in primary and secondary seals have on emissions.

Several important conclusions can be drawn from the data presented in Figure VI:

(1) If no secondary seal is present, toroidal seal gaps increase

emissions substantially over a "no-gap" toroidal seal.

(2) If a secondary seal is present above a toroidal seal, the emissions can be lower than with the "no-gap" toroidal seal even when overlapping, diametrically opposed 1/2" wide gaps over 6.4% of the tank circumference are present in both seals.

(3) If no secondary seal is present the emissions from a shoe seal system are less than from a "no-gap" toroidal seal system even when gaps up to 1-3/4" for 39.6% of the tank circumference are present in the shoe seal system.

(4) Emissions from a shoe seal system increase appreciably only when the gaps extend continuously for a considerable percentage of the tank circumference.

(5) If a secondary seal is present above a shoe seal the emissions can be lower than the "no-gap" shoe seal even when substantial gaps are present in both seals.

(6) A secondary seal on a riveted tank is an effective emission control device even under worst-case conditions.

Emissions Comparisons

Figure VII shows some comparisons between predicted emissions using the API-2517 equation and the CBI data base. Bars numbered 1 through 3 and 8 are for a welded tank equipped with a shoe seal. Bars numbered 4 through 7 are for a riveted tank equipped with a shoe seal. Bars 9 and 10 are for a welded tank equipped with a toroidal seal.

Bars numbered 1, 4, 5 are calculated by the API-2517 equation for a welded tank with or without a secondary seal, a riveted tank without a secondary seal, and a riveted tank with a secondary seal, respectively. Bars numbered 2, 3 and 6, 7 are calculated by using appropriate emission values from the CBI data for various ranges of circumferential gap openings between the primary shoe seal and tank shell, and weighting these emission values by the percent of time the respective gap openings are expected to be encountered in a field tank. The latter numbers were determined from the tank survey data in the Engineering Sciences reports.(4) For bars 3 and 7, the CBI data for 3/4" gaps over approximately 10% of the tank circumference in the secondary seal were used. Bars numbered 8, 9 and 10 use the CBI data for a "no-gap" shoe seal, "no-gap" toroidal seal, and a 1/2" x 6.4% of circumference gap in both the toroidal and secondary seals, respectively.

The following conclusions can be drawn from Figure VII:

(1) Emissions from shoe seal equipped floating-roof tanks are considerably lower than predicted by the API-2517 equation.

(2) The average emission levels from welded or riveted tanks equipped with shoe seals and no secondary seals are low and differ only slightly between the two tank types.

(3) The presence of a reasonably well fitting secondary seal which goes from the roof to the tank shell can further reduce the low emissions of a shoe-sealing system.

(4) The average emissions expected from a sealing system which employs both a primary and a secondary seal, with gaps in both seals, are lower than the emissions from a "no-gap" primary seal alone.

(5) When a reasonably well fitting secondary seal, which goes from the roof to the tank shell is used, the average emissions from equivalent welded and riveted tanks should be about the same.

Acknowledgments

The efforts of the WOGA Task Force members are gratefully acknowledged. These members were:

Jerry Adams	Fletcher Oil & Refining Co.	Wilmington, CA.
Earl K. Dewey, Jr.	Continental Oil Company	Ponca City, OK.
Dennis Dykstra	Chevron U.S.A., Inc.	El Segundo, CA.
John A Glaser	Gulf Oil Company, U.S.	Santa Fe Springs, CA.
Gordon J. Good	The Standard Oil Co. of Ohio	Cleveland, Ohio
Hayden H. Jones	Union Oil Co. of California	Wilmington, CA
Peter E. Jocker	Union Oil Co. of California	Los Angeles, CA.
Peter L. Melta	Atlantic Richfield Company	Carson, CA.
Richard A. O'Hare	Shell Oil Company	Carson, CA.
William J. Porter	Chevron, U.S.A., Inc.	El Segundo, CA.
Robert M. Stoneham	Texaco, Inc.	Wilmington, CA.

References

1. API Bulletin 2517, *Evaporation Loss From Floating-Roof Tanks*, American Petroleum Institute, New York, 1962.

2. (a) *SOHIO/CBI Floating Roof Emission Test Program, Preliminary Information*, Chicago Bridge & Iron Company, August 27, 1976.

   (b) *SOHIO/CBI Floating Roof Emission Test Program, Interim Report*, Chicago Bridge & Iron Company, October 7, 1976.

   (c) *SOHIO/CBI Floating Roof Emission Test Program, Final Report*, Chicago Bridge & Iron Company, November 18, 1976.

3. API Bulletin 2512, *Tentative Methods of Measuring Evaporation Loss From Petroleum Tanks and Transportation Equipment*, American Petroleum Institute, New York, 1957.

4. (a) *Evaluation of Hydrocarbon Emissions From Floating-Roof Petroleum Tanks, Interim Report*, Engineering Science, Inc. December 1, 1976.

   (b) *Hydrocarbon Emissions From Floating Roof Petroleum Tanks*, Engineering Science, Inc. January 1977.

5. (a) *Western Oil and Gas Association, Metallic Sealing Ring, Emission Test Program, Interim Report*, Chicago Bridge & Iron Company, January 19, 1977.

   (b) *Western Oil and Gas Association, Metallic Sealing Ring, Emission Test Program, Final Report*, Chicago Bridge & Iron Company, March 25, 1977.

   (c) *Western Oil and Gas Association, Metallic Sealing Ring, Emission Test Program, Supplemental Report*, Chicago Bridge & Iron Company, June 30, 1977.

Figure I

TYPICAL SHOE SEAL

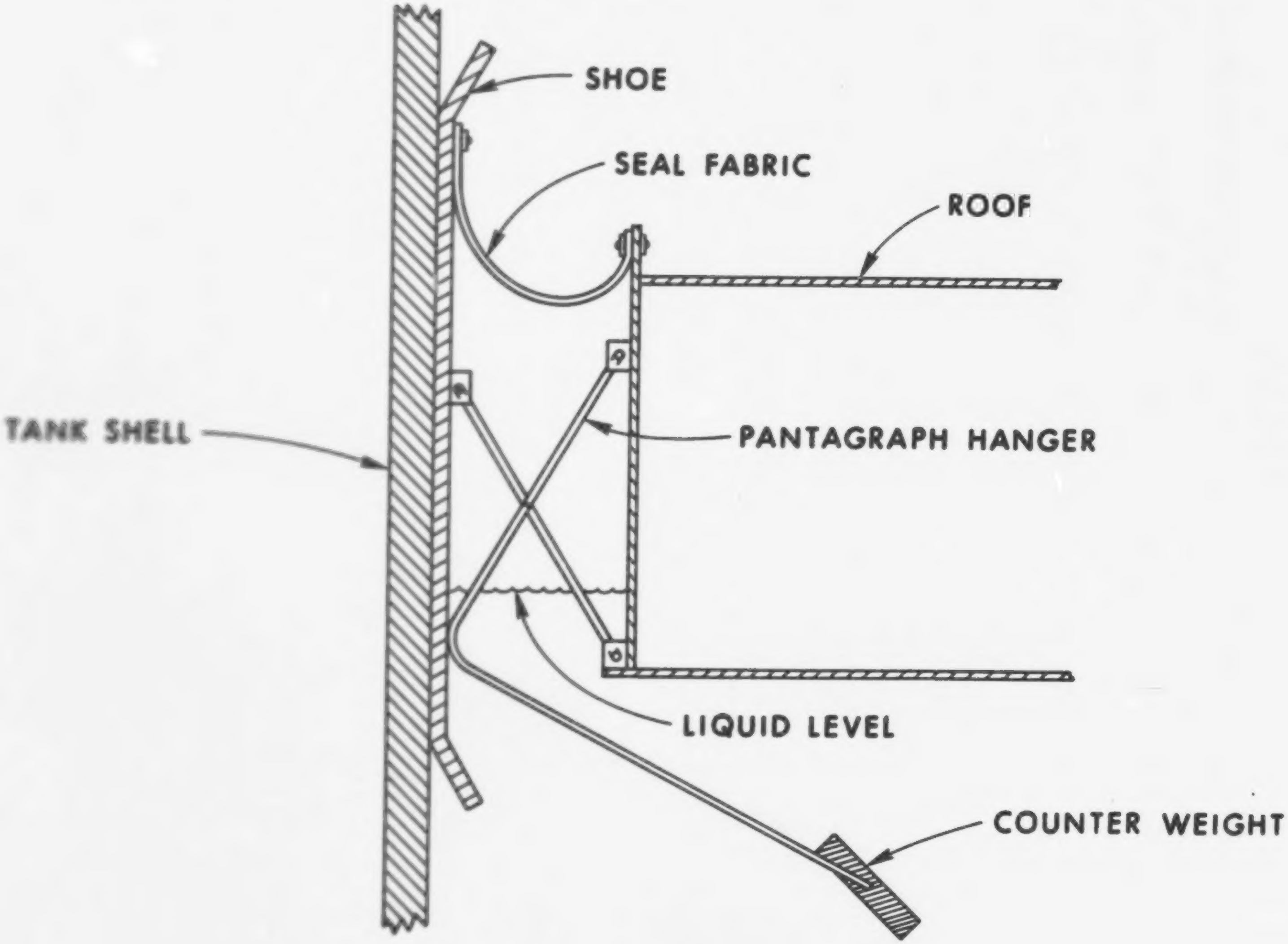

SHOE
SEAL FABRIC
ROOF
TANK SHELL
PANTAGRAPH HANGER
LIQUID LEVEL
COUNTER WEIGHT

Figure II

TYPICAL TOROIDAL SEAL

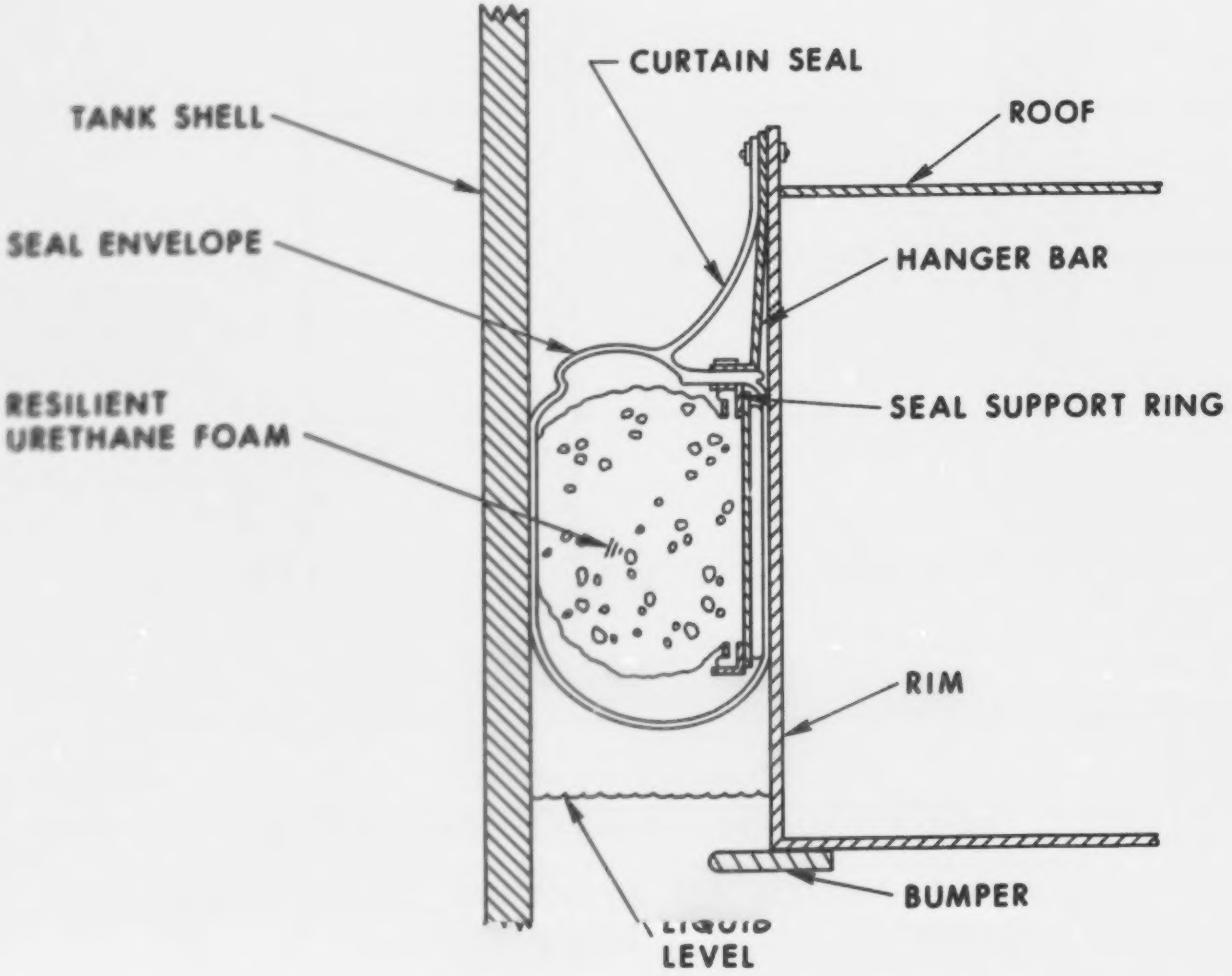

CURTAIN SEAL
TANK SHELL
ROOF
SEAL ENVELOPE
HANGER BAR
RESILIENT URETHANE FOAM
SEAL SUPPORT RING
RIM
BUMPER
LIQUID LEVEL

Figure III

EMISSIONS FROM 13 GASOLINE TANKS

WOGA/ENGINEERING — SCIENCE STUDY

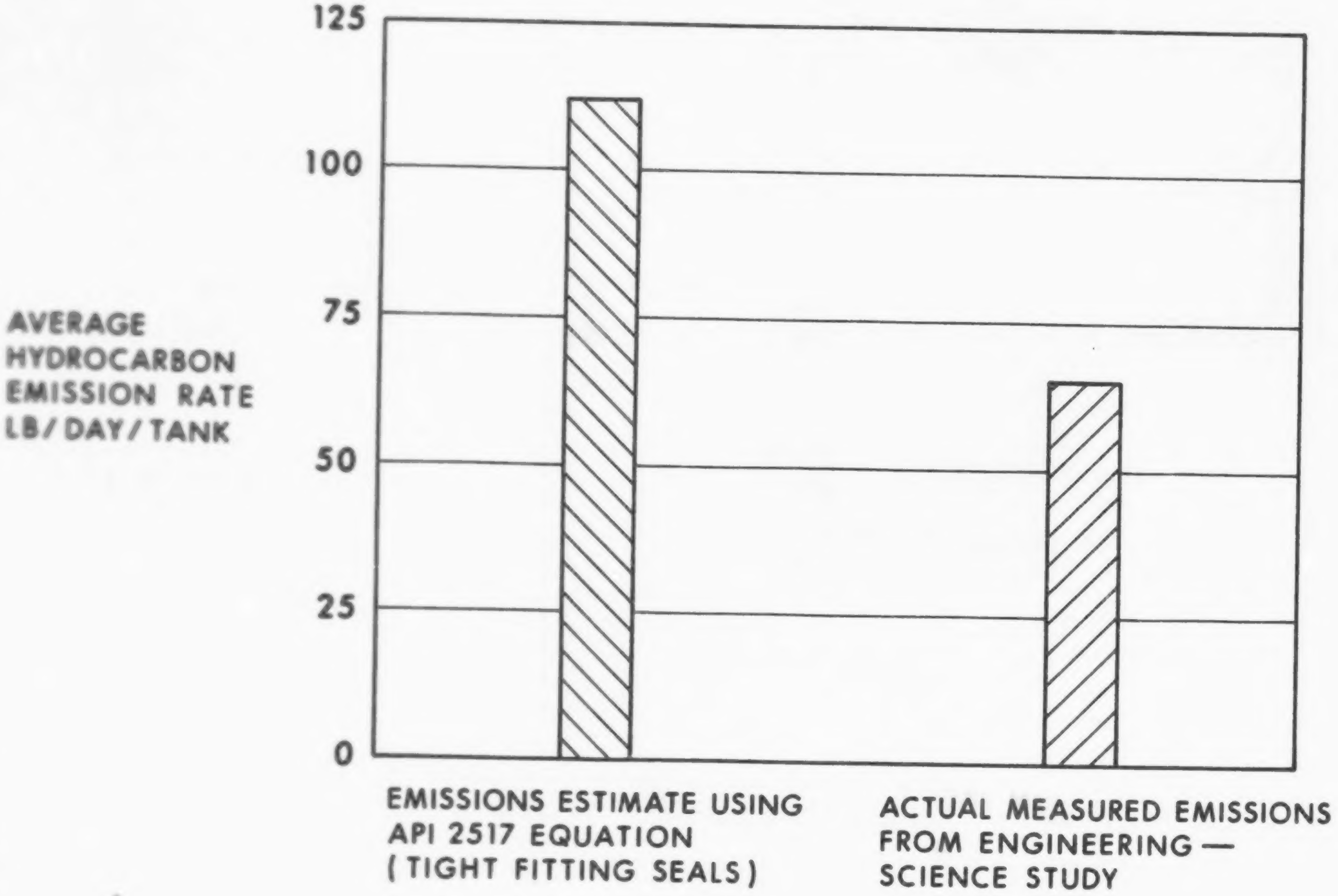


Figure IV

EFFECT OF WIND SPEED
CBI PILOT SCALE TANK

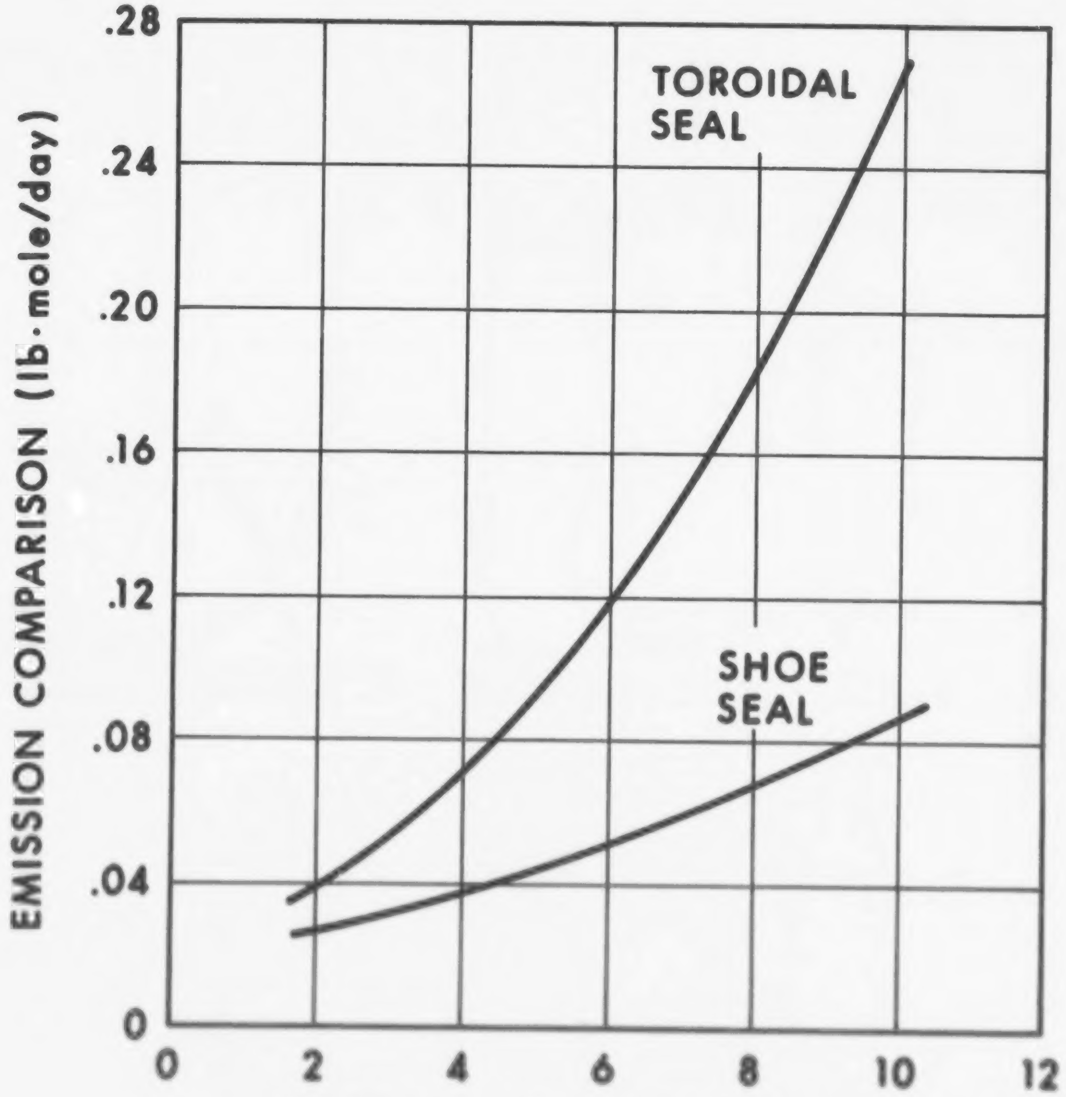


Figure V

TYPICAL SECONDARY SEALS

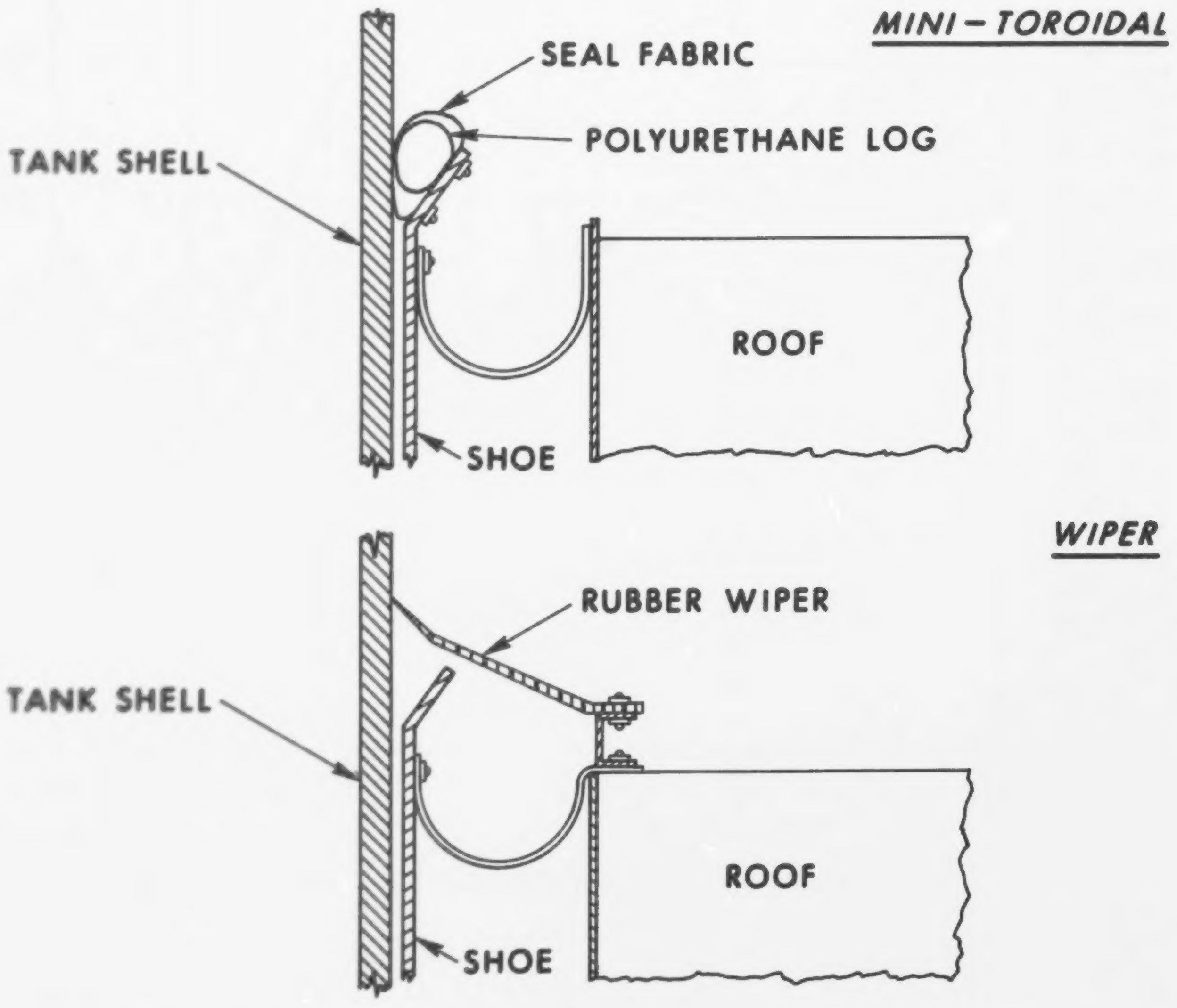
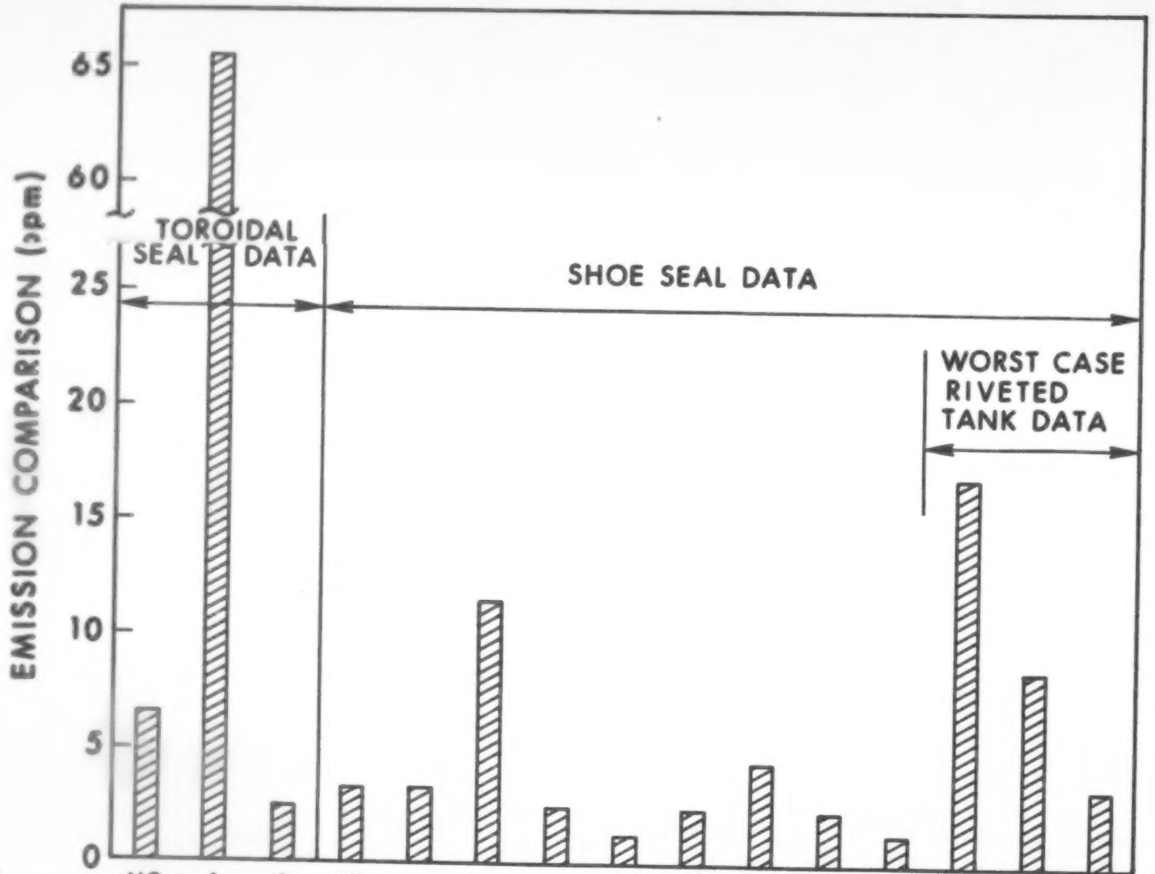

MINI – TOROIDAL
SEAL FABRIC
POLYURETHANE LOG
TANK SHELL
ROOF
SHOE
WIPER
RUBBER WIPER
TANK SHELL
ROOF
SHOE

Figure VI

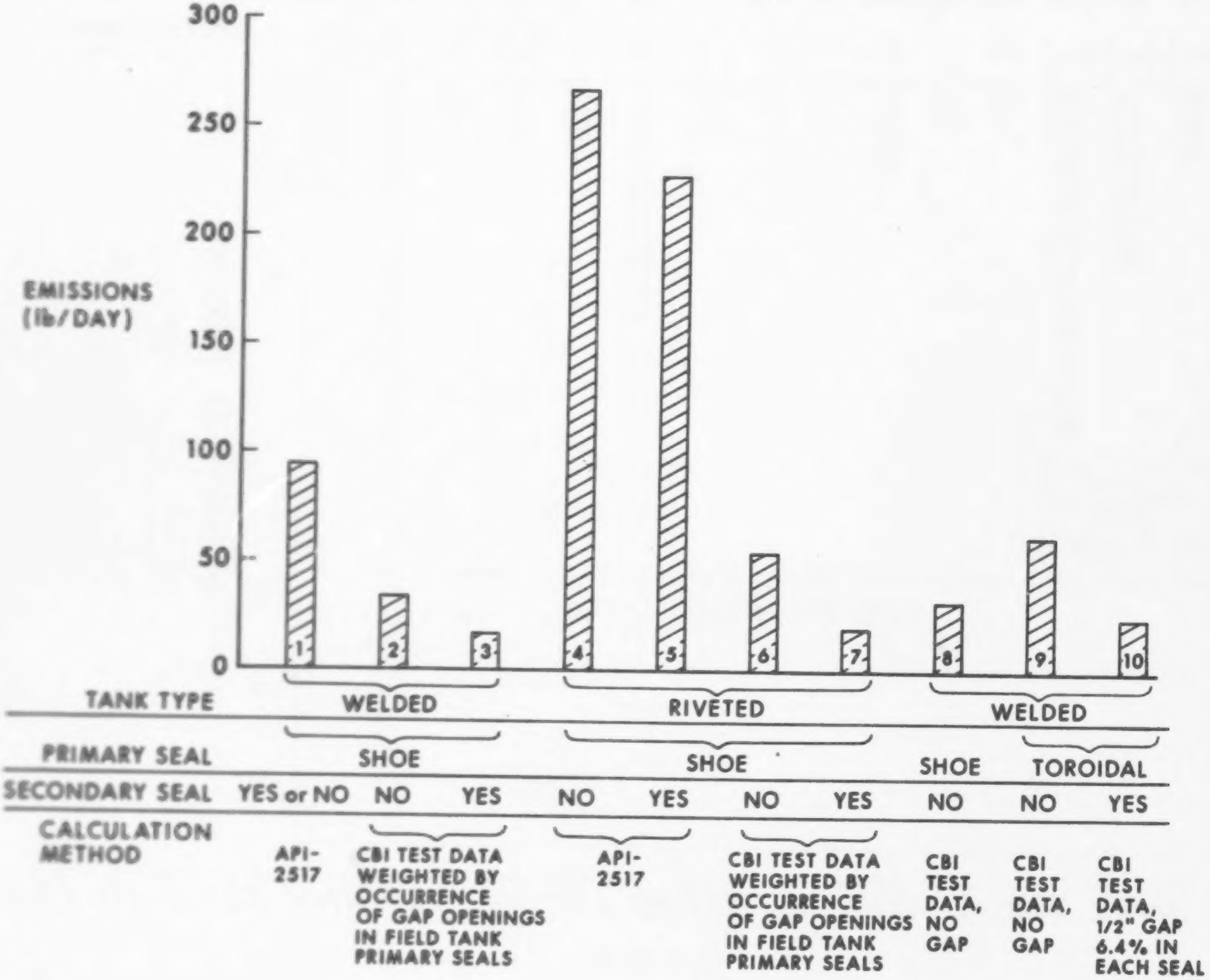
EFFECT OF GAPS AND SECONDARY SEALS CBI PILOT SCALE TANK DATA



PRIMARY SEAL MAXIMUM GAP, IN.	NO GAPS	1/2	1/2	NO GAPS	1	1/2	1/2	1/2	NO GAPS	1 3/4	1 3/4	1 3/4	3/4 → 1 1/2	3/4 → 1 1/2	3/4 → 1 1/2
% OF CIRCUMFERENCE		6.4	6.4		13.6	52.0	52.0	52.0		39.6	39.6	39.6	100	100	100
SECONDARY SEAL MAXIMUM GAP, IN.	None	None	1/2	None	None	None	3/4	1/2	None	None	3/4	1/2	None	3/4	3/4
% OF CIRCUMFERENCE			6.4				9.3	7.4			11.1	4.3		21.2	9.5

Figure VII

EMISSION COMPARISON FOR 150 FOOT DIAMETER TANK STORING 5 PSIA STOCK



CONDENSED DISCUSSION

QUESTION: I have no problem in inspecting a floating roof seal. I have a great deal of trouble inspecting the seal on an internal floater. Could you explain how you got in there and measured all those gaps on internal floaters?

RUSSELL: We didn't. We haven't done it on the internal floaters. Not that I am aware of anyway.

QUESTION: Originally you started out and said that because of the gaps, the California board evaluated that emissions were four times higher. With your new data would the emissions be two times or three times higher now?

RUSSELL: The new data shows that the emissions are 50% less than what would be calculated using the straight forward API equation. CARB was using the API equation and then increasing it by two to four times, so the new data says that we are considerably less than by four to eight times what CARB originally estimated.

QUESTION: I noticed in one of your emission loss factors for breathing loss that you used a constant breathing loss factor for I assume your used control tanks without any vapor returns.

RUSSELL: The vapor return wasn't installed to control breathing losses. Breathing losses are more or less uncontrolled.

COMMENT: But you used one factor and you said you based it upon API. API is based upon the breathing loss as a function of the amount of temperature rise during the day.

RUSSELL: We had to make some assumptions based upon the survey data as far as average tank size. Most tanks were in the same size range.

COMMENT: Well, regardless of size it depends on what the average temperature was.

RUSSELL: Yes, I think we used 15 degree daily temperature variation.

QUESTION: In the work did you establish the relative estimated condition level from small bulk plants as compared to bulk terminals?

RUSSELL No. The studies that we performed were dealing only with bulk plants - less than 20,000 gallons. This data was submitted to EPA to formulate or to determine how proposed vapor recovery regulations will effect small bulk plants. So we weren't really concerned with large terminals.

EMISSION INVENTORY OF PETROLEUM STORAGE AND HANDLING LOSSES
(A CASE HISTORY)

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

James T. Alexander, Jr.
Regional Engineer
Virginia State Air Pollution Control Board
Northern Virginia Office
Falls Church, Virginia 22043

Abstract

Gasoline and distillate products emissions were calculated for the Northern Virginia sector of Metropolitan Washington for the peak oxidant month of July using factors adjusted for specific July weather conditions. Sources included floating roof and fixed roof storage, bulk terminal loading racks, service station delivery and sales, airports, and small bulk plants.

Calculations were made in lbs/day and lbs/6-9 a.m. peak period under summer weather conditions typical for the high oxidant periods experienced in the region. The basis for emission factors was the Radian Corporation Study of August 1976 by Burklin and Honerkamp. Their version of the API empirical equation for floating roof losses was used in the absence of a better predictive model, recognizing the lack of correlation shown in January 1977 by Engineering-Science.

As expected, this method of inventory produces a great deal more emissions compared with year-around averaging of gasoline throughput and nationwide temperatures. Nearly all the differences are additive. Some are quite large. For example, gasoline vapor pressure at 79°F is 36% higher than it is at 60°F.

An earlier inventory for 1972 was re-calculated and the emissions were 70% greater using the July-specific inventory procedure. The effect of vapor control measures was determined. Overall reductions of 38% are shown on a lbs/day basis and 42% on

a lbs/peak period basis.

Correction by the Radian Study of the apparently erroneous data in AP-42 for properties of distillate fuels results in very small emissions from those products in the Northern Virginia region.

EMISSION INVENTORY
OF PETROLEUM STORAGE AND HANDLING LOSSES
(A CASE HISTORY)

James T. Alexander, Jr., Regional Engineer
Virginia State Air Pollution Control Board

Background

The cities and counties of Northern Virginia included in the National Capital Interstate Air Quality Control Region contain eight pipeline terminals and fourteen small bulk plants serving a greater metropolitan area of about three million people. Air quality exceeds the photochemical oxidant standard by 25% or more for about 35 days each summer. The Virginia portion of the region has very little industrial activity and comprises suburban and rural development characterized as "bedroom" communities. Gasoline vapor control measures were initiated in 1973.

Inability to apply, up to this time, an air quality simulation model that relates hydrocarbon and nitrogen oxides emissions to oxidant concentrations highlighted a need for better emission inventory of pollutants as an interim yardstick of control effectiveness during continued population growth. One portion of this inventory effort covered petroleum storage and handling emissions in Northern Virginia. These were calculated for 1976 and recalculated for 1972 using best available emission factors adjusted for local conditions. The paper describes how this was done and compares the results with an earlier, less precise, inventory.

The work involved two steps. First, the calculation of emission factors based on local conditions and second, the inventory of individual Virginia sources using those emission factors.

Local Meteorological Conditions

At the outset it was decided to calculate emissions in lbs/day for July conditions and to convert those emissions to lbs/6-9 a.m. period. July was determined to be the peak oxidant month. Based on 30-year weather observations at National Airport, July has 30% more days with maximum temperature 90°F or higher than either June or August. Studies have shown maximum temperature to be a useful surrogate for numerous meteorological variables that relate to peak oxidant formation in the Eastern U. S.[1] Data for the 6-9 a.m. period was sought so as to facilitate subsequent use of the Dodge-Demitriades smog chamber curves as an air quality simulation model. It will be recalled that the units of NMHC concentration plotted on those curves are in ppmC (6-9 a.m.)[2]

Table I shows local July meteorological factors for Washington National Airport compared with the nationwide annual values normally used in calculating evaporative emission factors for use in the National Emissions Data System (NEDS). Local values for the 6-9 a.m. period were taken for July 1976, a month which happened to conform quite closely to the 30-year mean for July.

Above ground storage temperature at 6-9 a.m. was assumed to coincide with the ambient daily mean. It was considered that early morning temperature depression from the ambient mean is probably offset by heating due to delivery of hot products from the pipelines. Products are known to be received in summertime as high as 90°F. This assumed product temperature was backed by sampling delivery truck loading tickets.

For below ground storage, the 6-9 a.m. ambient mean was used. That value is comparable with a number of local summertime tank measurements made during Stage I vapor balance testing. Many service station tanks are subject to external heating from absorption through black-top paving, and do not cool down during the pre-dawn period to the temperature of grass or dirt-covered subsurfaces.

Gasoline Distillation Properties

The largest distributor in the region, EXXON Company (U.S.A.), was asked to furnish data on Reid vapor pressure and API° gravity that could be considered typical for summertime gasoline products. They reported data for their three grades of gasoline that were marketed locally in July 1976. The sales-weighted values were: RVP-9.7 and liquid density - 6.16 lbs/gal.

Table II shows the resulting values of true vapor pressure at the assumed temperatures shown in Table I. The column titled "multiple" indicates the local value compared with the nationwide value as 1. In equations where emissions vary directly with true vapor pressure, or in the exponential form shown, the summertime temperature effect is pronounced.

Empirical Equations for Evaporative Losses

Initial attempts to use the empirical equations developed by the American Petroleum Institute in 1962, cited in the Air Pollution Engineering Manual, AP-40 (2nd Edition),[3] to derive localized emission factors were unsuccessful. The losses expressed in the API equations are in volumetric units (barrels of vapor emitted per year or per million barrels throughput). Physical properties of the vapor which are needed to convert emissions to a weight basis were not available.

Additionally, the empirical equations cited in AP-42 (Supplement One)[4] could not be used to calculate the "standard" evaporative factors contained in Section 4.3 of that document. Although those equations express losses on a weight basis, the vapor properties used in the equations apparently differ from those used to calculate the standard factors in Table 4.3-2. Values for true vapor pressure of distillate products used in AP-42 are apparently in error.

As a result of these shortcomings, the Federal EPA awarded a contract to the Radian Corporation, Austin, Texas to upgrade and refine the information presently contained in AP-42. Their report, prepared by C. E. Burklin and R. L. Honerkamp,[5] was obtained and the empirical equations contained therein were used to derive July emission factors for Metropolitan Washington. (This document is hereafter cited as "EPA-450/3").

Since the empirical equations contain factors for tank geometry as well as vapor pressure, local data was collected for tank diameters and tank vapor space height and estimates were made for paint condition. Average storage tank sizes at the eight bulk terminals in Northern Virginia were found to be slightly smaller than the nationwide average used for calculating standard factors in EPA-450/3. Table III shows these differences. Since tank diameter appears as an exponential function in the equations, these tank size differences are significant.

Emission Factors for Bulk Terminals

Local emission factors were computed for floating roof storage, fixed roof storage and loading rack emissions using the pressure, density, temperature, wind speed, and tank paramenters described above.

A comparison of the local values with the "standard" values in the Radian study, EPA-450/3, is shown in Table IV. The column titled "multiple" shows the ratio of the local factor divided by the standard factor. The local gasoline factors are 1.15 to 1.30 times the standard factors. This has an important bearing on the precision of an overall inventory.

The local fixed roof factors for breathing loss are smaller than standard values because of the smaller average tank diameter used in the equations. As will be shown, jet kerosene and No. 2

fuel oil emissions are quite small in comparison with gasoline, so an emission factor refinement for those products is not as important as it is for gasoline. This was not the case when AP-42 standard emission factors were used. The values in Table 4.3-2 of that document for distillate products are 8 times larger for breathing and 37 times larger for working losses than corresponding values in EPA-450/3.

It is recognized that floating roof emission factors based on empirical relationships must be regarded with some skepticism. The Radian Study did not correct basic inadequacies in the API empirical equation for floating roof standing storage emissions. Recent tests by Engineering-Science, Inc. on thirteen tanks in California revealed a marked lack of correlation between observed and calculated emissions.[6] It appears likely that further testing will show that well-designed internal floating pans result in less emissions than external floating decks that are subject to more wind effect.

Efficiency of Gasoline Vapor Recovery Systems

The empirical equations in EPA-450/3 provide a means to include the effects of gasoline vapor recovery at a known level of efficiency. Loading rack losses are effected by: (1) whether trucks return vapor collected by vapor balance at service stations, and (2) whether the loading racks themselves are controlled by onsite processing equipment.

Northern Virginia has Stage I vapor balance control on underground storage tanks at nearly all service stations. It is estimated that 90% of the gasoline throughput is so controlled. Vapor processing units are installed at each bulk terminal to liquify or incinerate the vapors displaced from truck compartments during reloading.

While the efficiency of these processing units was measured at 92-95%, extensive leakage is currently being experienced at truck compartment dome covers and truck vapor manifold fittings such that a significant amount of vapor is discharged during re-loading. For emissions factor calculation it was assumed that only 76% vapor recovery occurs at the loading racks. Applying .92 unit efficiency to .76 recovery efficiency yields an estimated .70 for overall loading rack efficiency for Northern Virginia terminals.

With that efficiency inserted in the empirical equation for loading rack losses, the local factor with dedicated trucks in vapor balance service becomes 3.3 lbs/10^3 gal.

The same computations for 70% loading rack efficiency, but without vapor balance at the service stations, yield 2.0 lbs/10^3 gal for local temperature conditions.

Table V shows gasoline loading rack losses under each of the various conditions.

Emission Factors for Service Stations

The passenger car refueling loss equation developed by Scott

Laboratories in 1972[7] was not used by Radian Corporation in EPA-450/3 nor are any empirical equations suggested in that report. It simply states certain values for service station losses without defining the standard ambient conditions for which they apply.

If it is assumed that the values in EPA-450/3 for service station losses are more accurate than earlier references[4,7] and that they are based on the same 60°F conditions used for above-ground storage, one could factor them up to 75.5°F by applying the vapor pressure multiplier (1.29), the number shown in Table II. That of course assumes the losses are directly proportional to true vapor pressure. For purposes of this inventory, that procedure was followed and local values were derived as shown in Table VI.

Conversion to the 6-9 a.m. Period

The development of factors to convert emissions in lbs/day to lbs/6-9 a.m. period is not susceptible to rigorous derivation. It is difficult to determine, for example, how much of the total service station monthly throughput is handled daily, let alone during the exact hours between 6 and 9 a.m. Table VII shows the conversion factors estimated for petroleum storage and handling operations in Northern Virginia during summertime. The percentage is the portion of 24 hour emissions that occurs during the three hours 6 to 9 a.m.

Storage Capacities and Volume Throughput

One final step before emissions can be computed is to determine, for each source and each product, the storage capacities and volume throughput. Gasoline volumes are greater in summertime and heating oil volumes are smaller, so for this analysis, source owners were asked to report volumes for the 31 calendar days of July 1976.

Using July data in the Eastern U. S. has an appreciable effect. Statewide gasoline tax data for Virginia over the past four years shows that July sales are between 6% and 10% higher than the 12-month average.

Volumes were converted to a daily basis by considering July a 31-day month for 7-day a week operations and a 26-day month for 6-day operations.

Inventory Results

Table VIII shows the inventories for July 1972 and July 1976 based on the local emission factors described herein. Gasoline sales during the four-year period were up 23%. Control measures resulted in an overall emission decrease of 35%.

Table IX shows the comparison with an earlier 1972 inventory based on AP-42 emission factors calculated on a tons per year basis. The total emissions are 71% greater using the procedure described in this paper.

Table X shows the July 1976 inventory for the three bulk terminal locations by petroleum products. The effect of the very small emission factors for jet kerosene, diesel and No. 2 fuel oil is shown. Although distillate products account for 22% of the throughput they generate less than 2% of the emissions. As noted previously, floating roof standing storage losses were calculated from an empirical equation known to be inadequate. Those emissions are 9% of the bulk terminal losses.

Table XI shows the effect of vapor recovery control measures in Northern Virginia. Without Stage I vapor balance at service stations and without vapor processing units at the terminals, emissions would be increased by 6343 lbs/6-9. This represents overall control of 42%.

Table XII shows the July 1976 emissions on a 24-hour basis in lbs/day instead of lbs/6-9 a.m. Comparing these figures with the previous data, Table VI, indicates the degree to which a 6-9 a.m. computation enhances overall control effectiveness. On a 6-9 basis it is 42%, while on a 24-hour basis it is 38%.

Conclusions

Two general conclusions may be drawn from this analysis. First, assuming the vapor properties of distillate fuels have been correctly specified by the Radian Corp. study, evaporative emissions from those products are hardly worth the effort to inventory, at least in the quantities they are handled in Northern Virginia in summertime.

The second conclusion is that gasoline evaporative emissions should be computed for the same ambient temperature and weather conditions that prevail at the time those emissions have the most pronounced effect on air quality during the peak oxidant season.

It is to be hoped that future revision of Sections 4.3 and 4.4 of AP-42 will avoid standardized, national average (NEDS) emission factors for gasoline evaporative emissions and portray the factors based on regional peak oxidant season conditions. This could be done with temperature correction factors similar to those used in calculating vehicle emissions.

References

1. Meteorological Conditions Conducive to High Levels of Ozone, T. R. Karl and G. A. DeMarrais, EPA (RTP) Paper Presented Sept. 12, 1976 at International Conference on PCO_x Pollution and its Control, Raleigh, N.C.

2. Alternatives for Estimating the Effectiveness of State Implementation Plans for Oxidant, Draft Paper, January 1977, OAQPS, EPA (RTP).

3. Air Pollution Engineering Manual (AP-40, Second Edition), J. A. Danielson, Los Angeles APCD, May 1973, (pp. 632-642).

4. Compilation of Air Pollutant Emission Factors (AP-42, Second Edition), February 1976, OAQPS, EPA (RTP) (Sections 4.3 and 4.4 by W. M. Vatavuk and R. K. Burr, dated July 1973).

5. Revision of Evaporative Hydrocarbon Emission Factors, (EPA-450/3-76-039) C. E. Burklin and R. L. Honerkamp, Radian Corporation, Austin, Texas, August 1976 (EPA Project Officer: C. C. Masser; Contract No. 68-02-1889).

6. Hydrocarbon Emissions from Floating Roof Storage Tanks, Engineering-Science, Inc., Arcadia, California, Jan. 1977 (Report prepared for Western Oil and Gas Association).

7. Investigation of Passenger Car Refueling Losses, (APTD-1453) M. Smith, Scott Research Labs, San Bernadino, California, Sept. 1972, (CRC Project CAPE 9-68).

TABLE I

	Nationwide Annual	Local July
Ambient daily mean temp.	60°	78.7°
Ambient daily Δ T	15°	15°
Ambient 6-9 am mean temp.	-	75.5°
Ambient 6-9 am Δ T	-	6°
Average daily wind speed	10 mph	8.1 mph
Average 6-9 am wind speed	-	7.3 mph
Assumed aboveground product temperature (6-9 am)	60°	78.7°
Assumed belowground product temperature (6-9 am)	60°	75.5°

Meteorological Factors

TABLE II

	Nationwide	Local	(Multiple)
Above Ground Storage	60°F	78.7°F	
P (psia)	5.2	7.1	(1.36)
$\left(\frac{P}{14.7 - P}\right)^{0.7}$	.6558	.9535	(1.45)
Belowground Storage	60°F	75.5°F	
P (psia)	5.2	6.7	(1.29)

True Vapor Pressure of Gasoline (RVP 9.7)

TABLE III

	Nationwide		Local	
	10^3 gal	D (ft)	10^3 gal	D (ft)
Floating Roof	2814	110	2298	94.2
Fixed Roof	2814	110	2098	87.1

Average Sizes of Storage Tanks

TABLE IV

	EPA-450/3	Local	(Multiple)
Floating Roof			
Gasoline Storage	.033[a]	.038[a]	(1.15)
Withdrawal	.023	.029	(1.26)
Fixed Roof			
Kerosene Breathing	.0045[a]	.0038[a]	(.84)
Working	.027	.044	(1.63)
No. 2 FO Breathing	.0040[a]	.0034[a]	(.85)
Working	.023	.037	(1.61)
Loading Rack			
Gasoline (uncontrolled)	5.0	6.5	(1.30)
Kerosene	.02	.03	(1.50)
No. 2 FO	.01	.02	(2.00)

---

[a] - lbs/day/10^3 gal; all others in lbs/10^3 gal

Bulk Terminal Emission Factors

TABLE V

($lbs/10^3$ gal)	EPA-450/3	Local	(Multiple)
Uncontrolled, w/o vapor balance	5.0	6.5	(1.30)
Uncontrolled, with vapor balance	8.0	11.0	(1.38)
70% control w/o vapor balance	---	2.0	---
70% control with vapor balance	---	3.3	---

Gasoline Loading Rack Factors (Submerged Fill)

TABLE VI

$(lbs/10^3\ gal)$	EPA-450/3	Local
Subm. Fill U. G. Tanks (w/vapor balance)	.30	.39
Breathing Loss U. G. Tanks (after fill)	1.0	1.3
Vehicle Refueling	9.0	11.6
Nozzle Drip and Spill	.7	.7

Service Station Emission Factors

TABLE VII

Gasoline	6-9 a.m. Factor (%)
Loading Rack	24
Filling U. G. Tanks	24
Filling Vehicle Tanks	18
Jet Kerosene	
Loading Refuelers	18
Loading Aircraft	18
Jet Kero, Diesel, No. 2 FO	
Loading Rack	24
Filling U. G. Tanks	24
All Products	
Storage	12.5

Peak Period Conversion Factors

TABLE VIII

No. Virginia	July 1972 lbs/6-9	%	July 1976 lbs/6-9	%
Bulk Terminals	6377	47.9	3764	43.5
Bulk Plants	349	2.6	195	2.3
Airports	209	1.6	37	.4
Controlled Serv. St.	0	-	3877	44.7
Uncontrolled Serv. St.	6365	47.9	784	9.1
Totals	13,300	100.0	8657	100.0

THC Evaporative Emissions

TABLE IX

No. Virginia	Original Annual 1972 lbs/6-9	%	Re-calculated July 1972 lbs/6-9	%
Bulk Terminals	3200	41.0	6377	47.9
Bulk Plants	180	2.3	349	2.6
Airports	200	2.6	209	1.6
Controlled Serv. Sta.	0	0	0	0
Uncontrolled Serv. Sta.	4220	54.1	6365	47.9
	7800	100.0	13,300	100.0

Re-calculation of 1972 Inventory

TABLE X

No. Virginia Bulk Terminals	Emissions (lbs/6-9) from		
	Gasoline	Distillate	
Fairfax	1813	28	
Newington	1674	23	
Manassas	225	1	
Totals	3712	52	(1.4%)
L. R. Volume (10^3 gals)	4105	1170	(22.2%)

July 1976 Inventory for Bulk Terminals

TABLE XI

No. Virginia July 1976	Present Emissions (lbs/6-9)	If Uncontrolled (lbs/6-9)	
Bulk Terminals	3764	6821	
Bulk Plants	195	266	
Airports	37	51	
Controlled Serv. Sta.	3877	0	
Uncontrolled Serv. Sta.	784	7862	
	8657	15000	(+6343)
Control Effectiveness			42%

Effect of Vapor Control Measures (6-9 am basis)

TABLE XII

No. Virginia July 1976	Present Emissions lbs/day	If Uncontrolled lbs/day	
Bulk Terminals	17,060	29,800	
Bulk Plants	878	1,157	
Airports	160	220	
Service Stations	24,480	37,820	
Totals	42,578	68,997	(+26,419)
Control Effectiveness			38%

Effect of Vapor Control Measures (24-hour basis)

CONDENSED DISCUSSION

QUESTION: At your terminals in airports, you had uncontrolled emissions. Is that looking at a tank without an internal floating roof?

ALEXANDER: Yes, I took the internal floaters and just factored them off as though they weren't there. We've got other parts of the state in Virginia that have no hydrocarbon regulations at all and it's kind of useful for them to see what would happen if they had the same regulations that we have in northern Virginia.

QUESTION: You did the analysis for July for the petroleum storage, etc?

ALEXANDER: That's right.

QUESTION: Now to put those emissions into prospective with other sources of hydrocarbons. Did you also calculate hydrocarbons from other sources for July? Namely automobiles, natural sources, what have you?

ALEXANDER: This is a very very good point. If you are going to run a July inventory for one source you should run it for all sources. I regret to say that we simply don't have the technique to do this.

QUESTION: Do you record any relationship between July inventory and the rest of the other eleven months of that year? Is it 10%, 20% higher than an average month?

ALEXANDER: By comparing the 72 inventories that we had made - the old July to new July 76 hydrocarbons were up 70% on the basis of using the July weather conditions as opposed to averaging the month of July out of a 12 month inventory.

INVENTORYING HYDROCARBON EMISSIONS FROM SMALL GASOLINE BULK PLANTS

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

R.L. Norton and R.J. Bryan
Pacific Environmental Services, Inc.
1930 14th Street
Santa Monica, California 90404

ABSTRACT

This paper describes the technique used to inventory hydrocarbon emissions for nearly four hundred gasoline bulk plants in the San Joaquin Valley and San Diego County areas of California, the Metropolitan Denver area, and the Houston/Galveston and Baltimore/Washington, D.C. air quality control regions. Updated throughput information and complete inventories of bulk plant operations were obtained. Emission estimates were generated for potential as well as controlled hydrocarbon losses within each study region. The paper describes the emission factors used and the methodology for presenting the emission estimates.

Problems encountered while attempting to obtain the inventory data are discussed and include: 1) the lack of an existing inventory, 2) the variation in the applicability of state regulations which in turn effected the quality of the data available (i.e. if the state did not regulate the bulk plants, there would be no information on them in their files), 3) inability to obtain operating data from some sources because of confidentiality claims, 4) problems in verifying all inventory entries from the various sources as bulk plants defined by the study.

I. Introduction

Environmental Protection Agency (EPA) regulations for the storage and transfer of gasoline require bulk plants in certain specified air quality control regions to control hydrocarbon emissions from their operations. A recent Federal Register (June 7, 1977) defines these air quality control regions and gives background information on the proposed regulations. These regulations require vapor recovery systems to be installed and operated in a manner that will prevent release to the atmosphere of no less than 90 percent by weight of organic compounds in vapors generated during gasoline transfer operations. Individual states have submitted control strategies in State Implemention Plans and enacted laws which frequently provide for the exemption of small bulk plants from hydrocarbon emissions control regulations. Conditions for granting these exemptions are not uniform among the states, e.g., throughput limits often differ. The rationale for allowing exemptions has generally been based on the anticipated adverse economic impact to the industry or on the estimated minor contribution of bulk emissions to the area wide hydrocarbon/oxidant levels.

In order to determine whether Federal vapor recovery regulations need revision, the Division of Stationary Source Enforcement (DSSE) contracted with Pacific Environmental Services, Inc. (PES) to perform a preliminary investigation of the impact of vapor recovery regulations on small bulk plants. This first study focused on bulk plants in the San Joaquin Valley and San Diego areas in California and the Denver, Colorado area. A similar survey of bulk plant operations in the specific areas surrounding Baltimore, Maryland and Washington, D.C. and Houston/Galveston, Texas was also performed to determine whether the descriptive, market and economic data presented in the first report could be adequately applied to other areas of the country. The tasks completed for both studies were quite similar:

1. Provide an inventory of bulk plants.
2. Describe facilities and vapor recovery equipment at the bulk plants.
3. Classify these bulk plants by throughput.
4. Determine types of customers and volume dispensed to non-exempt accounts, agricultural accounts and accounts with small tanks.
5. Determine the financial profile of typical bulk plants.
6. Estimate the long and short term economic effects of installing and maintaining vapor recovery equipment, particularly with respect to the number of anticipated plant closures or plant start-ups.
7. Estimate emissions from bulk plant operations and the decrease in emissions if controls are adopted.

This paper describes the survey techniques employed to inventory nearly four hundred bulk plants in the study areas. Methods for formulating emission estimates and problems associated with information gathering will also be discussed. Because of the current EPA interest in bulk plants, sections have been included on definition of emission sources and applicable hydrocarbon control concepts.

II. Description of Bulk Plants

A gasoline bulk plant lies in the gasoline marketing chain between the large terminal and the ultimate end user. The bulk plant, normally found in the rural areas, serves small customers where either the large truck transports cannot or will not deliver. The studies, within which the inventories were conducted, defined the small bulk plant to be one whose daily throughput was less than twenty thousand gallons of gasoline and one where all deliveries are made to and from the bulk plant by road. Although bulk plants may handle a variety of products, including gasoline, fuel oil, diesel fuel, etc., the derived emission estimates were only developed for gasoline.

The typical facility, as defined by the surveys, consisted of three or four above ground storage tanks, one delivery truck loading facility, two delivery trucks and a gasoline throughput of from five thousand to eight thousand gallons per day.

III. Inventory of Bulk Plants

A. Information Sources

The first step in inventorying the bulk plants in the five study areas was to determine the quality of the existing data base. The applicable EPA regional offices were contracted but little or no data on gasoline bulk plants existed in their files. Contacts at the state agencies in the study area were obtained from the applicable EPA offices.

The quality of the data available at these agencies was usually dependent upon whether or not the bulk plant emissions were covered under an applicable State Regulation. A fairly complete inventory of bulk plants was provided by the Virginia State Air Pollution Control Board and by the Maryland Bureau of Air Quality and Noise Control for work in the Baltimore/Washington, D.C. AQCR. The information provided included: 1) plant name and location, 2) plant gasoline throughput, 3) number and types of tanks, and 4) number and types of trucks, but the Maryland data was from 1974 and the Virginia data was from a 1972 survey.

The California Air Resources Board was also contacted as to the extent of data available on the number of bulk plants in the San Joaquin Valley AQCR and in San Diego County. The Air Resources Board supplied a summary of bulk plant operations for each county but did not indicate specific locations. Since the purpose of the studies was more than just an inventory and data was needed from the individual bulk plant operators, the ARB was again contacted and asked if they could supply the data from which the summary was made. The resultant information supplied consisted of copies of letter heads, business cards, return addresses and hand written notes. This information, which consisted of over 200 entries, was then organized by counties and the totals checked against the supplied summary data.

An initial inventory of bulk plants was supplied by the Colorado Department of Health, Air Pollution Control Division and supplemented by information from the Oil Inspectors Office. PES was informed that this inventory was the most up-to-date possible, but it was later found to be inaccurate. For example, the supplied list consisted of approximately twenty bulk plants. Four of these plants were out of business and approximately twenty-five additional bulk plants were identified.

The Texas Air Control Board was also contacted. There was no data available in the Texas office since the State Regulations were not applicable to bulk plants in the size range studied.

When there was no available information from the State offices or it was felt that the data might not be complete, the local air pollution agencies in the study areas were contacted. This included fourteen agencies in California, two in Texas and one in the Washington, D.C. area. The data obtained ranged from excellent to none at all, again, due mostly to the applicability of the local regulations. In some cases, written requests or personal visits were required to determine the availability of the data and to ensure that the data obtained was pertinent to the project. Written data requests for each bulk plant included the following:

- Bulk Plant Name
- Location
- Plant Contact (Owner/Operator)
- Gasoline Throughput
- Storage Tanks:
  - Number of Tanks
  - Above/Below Ground
  - Tank Capacity
  - Physical Size of Tanks
  - Splash/Submerged Fill
  - Vapor Recovery Apparatus (If Any)
  - Pressure-Vacuum Vent Setting & Type
- Plot Layout
- Delivery Trucks:
  - Size
  - Vapor Return
  - Splash/Submerged/Bottom Loading
- Loading Rack Controls:
  - Vapor Recovery System
  - Size of Vapor Return Line
- Accounts Breakdown (% Commercial, % Agricultural, And Percentage Exempt Under Vapor Recovery Regulations

Letters were sent to the San Joaquin, Stanislaus and Tuolumne County California Agencies and visits were made to the King and Kern County Agencies in California, The Texas Air Control Board, Houston Office and the Galveston County Health District in Texas, and the Colorado Health Department.

Governmental agencies were not the only sources of information and often times not the most productive. In each state involved, the applicable trade associations were contacted. These included the California Oil Marketers Association, Texas Oil Marketers Association, Maryland Oil Jobbers Council, Virginia Petroleum

Jobbers Association and the National Oil Jobbers Council. In many cases, the trade organizations were hesitant at first to supply the information because they were not sure as to the ultimate use of the data. Once they were assued that the information and the purpose of the project was not enforcement oriented, the data was generally supplied on the location of bulk plant operations in their regions. However, this data was limited to operations or operators that were members of these organizations.

Representatives from the major oil companies operating in each region were contacted as to the location of bulk plant operations. In most cases, the oil companies would not release the information because they felt that this was confidential. Others could not release the requested data because the operations were run by private businesses and the oil companies did not have the details of the business operations. Where information was provided by the oil company, (Standard Oil of California and Continental Oil Company in Denver) the data was included in the respective county inventories.

As a supplement to the sources of information already described, telephone directories in the study regions were consulted to ensure that all bulk plant facilities would be included in the inventory survey. The facilities developed from the several information sources were arranged into county groups to constitute the initial bulk plant inventory.

B. Verification of Bulk Plant Inventory

Once the initial list had been generated, it was decided that a verification of the operations as bulk plants, as defined by the studies, was necessary. Types of information obtained from the verification procedures included:

- identity of bulk plants which had shut down
- identity of plants included in the initial inventory which were not bulk plants as defined by the study
- identity of plants which had ceased handling gasoline
- identity of plants which had moved to locations not within the study boundaries.

Verification procedures were performed by on-site visits, by off-site visual verification or by telephone contact. In the five study areas, over eighty on-site visits were conducted and nearly 300 telephone contacts and visual verifications made. Visual verifications were often originally scheduled to be on-site visitations but time restraints in the field would not allow interviews to be conducted at each location. These visual verifications were followed up by telephone contacts to obtain additional data.

C. Data Gathering

To obtain updated information on the bulk plants and to provide a current data base for the emission estimates, data gathering was performed in conjunction with the various verification procedures described previously. The requested data included information on 1) plant gasoline throughput 2) storage tank number, size, contents and capacity, and 3) capacity and number of delivery trucks owned by the bulk plant operator. Forms were developed to obtain the pertinent operating data, to obtain information on control approaches employed, and to obtain other data which was necessary to complete the study. A copy of the inventory questionnaires is shown in Appendix A.

The data gathering was conducted by on-site interviews with the bulk plant operators and through telephone conversations. As can be expected, many of the operators and through telephone conversations. As can be expected, many of the operators were reluctant to release operating information on their particular businesses. This was especially true of the independent operator. The bulk plants which were operated through the major oil companies, either as consignees or as independent agents, were much more willing, on the whole, to divulge throughput information. In the case of a few major oil company operated bulk plants, though, the requested information would only be released after the operator received clearance from his marketing manager. This usually required PES to submit a written description of the project and to describe the need for the operating data. In all cases it was considerably easier to obtain operating data than it was to obtain financial data or the financial status of the operations, which was needed to complete the study.

When the verifications and data gathering tasks were completed, the county inventories were edited to include the most recent and accurate operating data. Tables I, II and III indicate summaries of the bulk plant inventories. Table I shows the average values for all bulk plants within the California and Colorado study areas and Tables II and III depict data from the actual interviews performed by PES in the Houston/Galveston and Baltimore/Washington, D.C. areas. Table IV summarizes the data obtained in the PES bulk plant inventories.

D. Problem Areas

Several problems arose in obtaining the inventory data from the numerous sources described above. The lack of an existing inventory in many areas made it difficult to generate a basis for the surveys. The wide variability of the regulations from state-to-state and county-to-county made data gathering very inconsistant. While one county may have a detailed list of bulk plants, the neighboring county may have no data at all. In many cases, the bulk plants were identified but the operators would not release any operating data because of confidentiality claims. Some operators would not release data because they were unhappy with Federal vapor recovery regulations and did not want to release information that they felt might be used for enforcement purposes.

Other problems arose in attempting to verify the initial entries into the inventories as bulk plants defined by the study. Since a bulk plant which had gone out of business could not be

Table I. SMALL GASOLINE BULK PLANT INVENTORY, SUMMARY OF CALIFORNIA AND COLORADO STUDIES

County	No.[a] of Bulk Plants	Avg. Gasoline Through-put Liters/ day[b]	GASOLINE STORAGE TANKS[c]				% of with Vapor Recovery on In-coming Loads	OUTGOING LOADS					CUSTOMER ACCOUNTS[h]	
			Avg. No. of Tanks	% of Plants with Above-Ground Tanks Only	% of Plants with Under Ground Tanks Only	Avg. Storage Capacity Liters[b] $x10^{-3}$		% of Top Load-ing	% of Bottom Load-ing	Avg. No. of Trucks	% of Plants with Sub-merged Fill	% of Plants with Vapor Re-covery	Avg. % Small Agri-cultural	Avg. % Service Stations
California														
Amador	1	16,600	3.0	100	0	101	0	100	0	N.D.	100	0	60	40
Calaveras	4	20,900	3.0	67	33	113	0	100	0	3.0	N.D.[d]	0	53	33
Fresno	47	26,800	3.6	66	21	227	42	89	11	2.4	70	5	67	27
Kern	35	13,100	2.6	77	23	144	91	100	0	2.1	90	0	49	N.D.
Kings	10	11,100	3.2	80	20	165	N.D.	100	0	2.2	100[e]	0	73	13
Madera	11	20,600	2.6	73	27	163	0	100	0	1.7	80	0	69	31
Mariposa	3	12,700	3.0	33	67	156	33	100	0	2.0	50	0	75	13
Merced	18	23,800	3.1	71	29	196	78	89	11	2.1	25	11	74	17
San Joaquin	21	11,700	2.9	67	22	177	29	75	25	2.0	78	0	13	44
Stanislaus	24	34,400	3.9	73	9	204	100[f]	N.D.	N.D.	2.0[e]	N.D.	N.D.	63	16
Tulare	31	25,500	3.2	52	45	178	72	97	3	2.2	79	7	73	15
Tuolumne	3	14,500	3.3	100	0	214	50	100	0	2.0	100	0	30	52
San Diego	10	17,400	2.4	40	60	115	80	40	60	2.2	90	60	57	43
Colorado														
Adams	7	19,700	2.6	86	14	117	20	100	0	1.7	N.D.	0	78	1
Arapahoe	4	38,000	5.3	67	33	179	0	100	0	2.0	100	0	18	57
Boulder	19	13,800	3.8	94	6	142	14	93	7	1.4	75	20[g]	60	39
Denver	13	23,600	2.9	50	50	146	22	90	10	2.1	100[e]	0	1	18
Jefferson	2	8,900	4.0	100	0	155	0	50	50	1.5	N.D.	0	15	50
Totals														
California	218	21,400	3.2	66	28	183	58	90	11	2.2	74	9	64	23
Colorado	45	19,200	3.5	79	21	142	18	92	8	1.7	86	7	44	31
Survey	263	21,100	3.2	68	27	177	53	90	10	2.1	74	9	61	25

NOTES:
a - Plants stated to be operating at time of survey
b - Divide by 3.785 to obtain gallons
c - Where totals do not equal 100, indicates plants with both above- and underground tanks
d - N.D. = no data
e - Only one response
f - Only three responses
g - Only four responses
h - Where totals do not equal 100, indicates other types of accounts served (commercial, large agriculture, etc.)

Table II. SUMMARY OF DATA OBTAINED ON BULK PLANTS IN HOUSTON/GALVESTON AREA

Plant Throughput		Exempt Accounts		Storage Tanks			Vapor Recovery	Account Trucks
		Farm	Non-Farm Tanks	Tanks	Capacity Thousand			
Gal/Day	L/Day	%	%	No.	Gal	L		Number
3,200	12,100	60	40	3A[a]	29	110	III[b]	3
5,700	21,500	60	40	3A	38	143	I[c]	2
18,200	68,800	10	90	4A	50	190	I, II[d], III	2 S[e]
9,100	34,400	20	10	3A	51	193	I, II, III	3 S
7,600	28,800	-	-	4A	-	-	-	2
11,400	43,000	40	20	3A	55	208	I, II, III	2 S
11,400	43,000	40	40	4A	48	182	I, III	2
11,400	43,000	50	40	5A	60	227	I, II, III	3 S
9,100	34,400	5	85	4A	50	190	I, II, III	2 S
6,400	24,100	70	29	3A	36	136	I, III	2
6,800	25,800	25	40	3A	50	190	I, II, III	3S
4,500	17,200	50	30	3U[f]	24	91	III	2
7,400	28,000	25	65	3U	30	114	I, III	3
9,100	34,400	1	20	3U	26	98	I, II, III	2 S
3,200	12,100	2	2	2U	36	136	I	1
4,500	17,200	5	0	2U	20	76	None	2
2,300	8,600	-	-	2U	20	76	-	-
8,300	31,500	33	-	3A	38	143	None	2
11,400	43,000	10	80	3A	42	159	I, III	2
3,200	12,100	50	48	3A	52	197	I	1
3,400	12,900	80	20	2A	35	132	None	1
5,000	18,900	25	75	3A	47	178	I, III	1
3,000	11,200	80	20	2A	56	212	None	1

Table II. SUMMARY OF DATA OBTAINED IN BULK PLANTS IN HOUSTON/GALVESTON AREA (continued)

Plant Throughput		Exempt Accounts		Storage Tanks			Vapor Recovery	Account Trucks
		Farm	Non-Farm Tanks	Tanks	Capacity Thousand			
Gal/Day	L/Day	%	%	No.	Gal	L		Number
7,700	29,200	5	15	4A	63	238	I, III	2
19,000	71,900	-	-	-	-	-	I, II, III	-
12,500	47,300	5	30	5A	70	265	I, II, III	3 S
2,300	8,600	33	67	3U, 6A	17	64	None	1
21,600	81,700	15	25	4A	53	201	I, III	3
4,500	17,200	40	0	4A	52	197	I, II	2
7,300	27,500	40	0	3A	36	136	I, III	2
18,200	68,800	-	-	4A	56	212	-	-

[a] A = Aboveground tank

[b] III = Vapor Recovery installed on at least one account truck

[c] I = Phase I Vapor control (Control of incoming gasoline transfers)

[d] II = Phase II Vapor control (Control of outgoing gasoline transfers)

[e] S = Submerged fill

[f] U = Underground tank

Table III. BULK PLANTS IN BALTIMORE/WASHINGTON D.C. AREAS INTERVIEWED BY PES

PLANT THROUGUPUT		RACK SALES		GASOLINE STORAGE			VAPOR RECOVERY[b]	ACCOUNT TRUCKS[c]
		FARMS	SMALL TANKS[a]	TANKS	CAPACITY, THOUSAND			
Gal/Day	1/Day	%	%	Number[d]	Gal	1		Number
15,400	58,000	0	70	2U	40	151	+	2
700	2,600	75	85	2U, 2A	41	155	-	3S
700	2,600	0	60	6U	34	129	-	1S
3,200	12,000	75	100	3U	22	83	-	1S
4,500	17,000	7	97	3U	34	129	+	1S
10,800	41,000	25	71	3A	61	231	-	5S
1,600	6,000	95	99	2U	30	114	-	1S
2,700	10,000	3	20	4A	80	303	+, I	2*
4,800	18,000	75	95	4A	80	303	-	4S
2,000	7,500	?	?	2U	24	91	-	1
6,800	26,000	15	25	3A	51	193	-	5
5,800	22,000	75	95	2A, 1U	58	219	+	1
3,600	14,000	75	75	3A	45	170	-	1S
1,900	7,300	78	99	1U,3A	50	190	-	2S
3,000	11,000	65	100	2U	40	151	+	1S
1,250	4,700	10	95	3U	26	98	+	1S
7,700	29,000	5	90	2A	240	908	-	4S
4,800	18,000	30	30	2U	30	114	+	3S
17,300	66,000	7	75	3U	90	341	+	1S
900	3,300	80	80	1A,1U	35	133	+	1S
1,500	5,500	25	45	2U,1A	50	189	-	1
1,500	5,800	85	99	2A,1U	34	129	-	2S
1,900	7,300	70	90	2A	20	76	-	3S
8,000	30,000	5	50	2A	40	151	-	1
5,500	21,000	50	100	3U	90	341	-	2
1,000	3,900	75	99	5A	69	261	-	4S
8,300	32,000	50	99	3A	45	170	+	2S

[a] Tanks less than 2,000 gal capacity (7600 1)

[b] Vapor recovery systems for control of incoming loads, + = yes, - = no; for control of outgoing loads, I = yes

[c] All plants surveyed, except one marked with asterisk, used only top-loading account trucks. S: submerged filling

[d] U = underground tanks; A = aboveground tanks

Table IV. SUMMARY OF SMALL GASOLINE BULK PLANT OPERATIONS

Areas	No. of Bulk Plants	Gasoline Storage Tanks				Ave. Storage Capacity Liters^a x10^{-3}	% Plants with Vapor Recovery on Incoming Loads	Outgoing Loads					Customers Accounts	
		Average Gasoline Throughput Liters/day^a	Ave. No. of Tanks	% Plants with Aboveground Storage	% Plants with Underground Storage			% Top Loading	% Bottom Loading	Ave. No. of Trucks	% Plants with Submerged Filling	% Plants with Vapor Recovery	% Throughput Agricultural	% Throughput Small Tanks^c
San Diego/San Joaquin Valley Areas	218	21,400	3.2	66	28	183	58	90	10	2.2	74	9	64	~77
Denver Area	46	19,200	3.6	79	21	142	18	92	8	1.7	86	7	44	~60
Baltimore/ Washington, D.C Area	56	16,900	3.0	45	56	192	37	96	4	2.1	67	0	46	79
Houston/ Galveston Area	70	31,600	3.5	80	20	182	75	90	10	2.0	34^b	46	~25	~50

[a] liters/3.7854 = gallons

[b] Submerged fill pipes in the trucks and not on the loading racks. If only properly equipped trucks are used to haul gasoline, then submerged filling becomes a more effective pollution reducing technique

[c] Less than 7,600 l. (2,000 gal) capacity, including agricultural tanks

contacted, this information had to come from other operators in the area. Some entries derived from local telephone directories could not be located or contacted and the information again had to come from a cooperative bulk plant operator in the respective area.

IV. Estimating Emissions Based on Bulk Plant Inventory

A. Sources of Emissions

Before the actual emission estimates could be performed, the sources of the emissions had to be defined. The hydrocarbon emission sources described here were determined from the numerous on-site inspections and interviews performed by PES personnel.

Emissions from bulk plants consist of vapor which can escape from storage tanks, even when there is no transfer activity, because of changes in temperature of the tank wall and stored materials which vary the pressure in the vapor space. Variation forces vapor-laden air out of the tank and aspirates fresh air into the vapor space, allowing further vaporization of gasoline into that space. The amounts of vapor escaping under these conditions are referred to as "breathing losses." Losses of vapors due to liquid transfer forces air-hydrocarbon vapors out during filling of the tank and ingests air (promoting evaporation) during draining. Miscellaneous or fugitive losses are primarily related to spillage and leakage during gasoline handling.

1. Breathing Losses

Factors affecting breathing or standing losses for fixed roof tanks include the amount and volatility of the gasoline stored, type and condition of tanks and appendages, and the prevailing meteorological conditions. If there are no leaks or direct openings, temperature fluctuation is the major cause of breathing losses. As the temperature of the liquid rises, the vapor pressure increases and evaporation takes place. The overall pressure in the gas space increases and when the vent pressure set point is exceeded, a mixture of air and hydrocarbons is discharged into the air. As the temperature decreases, gases partially condense, contract, and fresh air is drawn into the vapor space. This permits additional hydrocarbons to vaporize. Since hydrocarbons are emitted, but generally not drawn back into the tanks, a continued loss of hydrocarbon results from the daily changes in ambient temperature.

2. Working Losses

The principal cause of vapor loss during liquid transfer is displacement of the gas (air laden with hydrocarbon vapors) in the vapor space by the liquid entering the tank. Other causes include the entrainment of liquid droplets in the displaced gas and post-withdrawal pressure increase caused by evaporation.

Certain operating conditions can increase or decrease these vapor losses. Splash loading in which gasoline is dumped onto the surface of the liquid causes turbulence which increases evaporation rates and entrainment of droplets in the vapor being displaced. A short interval between emptying and filling of storage tanks can decrease losses by minimizing the time allowed for evaporation. Also, storage tanks can be emptied in increments over a period of several days or can be emptied in one operation prior to refilling, with resultant differences in vapor loss.

Assuming no controls, each time a gasoline tank is filled, the vapors above the liquid surface are emitted to the atmosphere. The quantity of hydrocarbon vapors emitted is a function of the volume displaced, type of loading, temperature and the degree of saturation of the vapor space with gasoline vapors. At any given temperature, the amount of vapor in the vapor space cannot exceed a limit imposed by the saturation pressure corresponding to that temperature. This limit, however, increases as the temperature increases.

In a quiescent state, the approach of saturation and pressure increase of a vapor space with gasoline vapors is a slow process. Since hydrocarbon vapors are heavier than air and diffusion is slow, a saturated blanket of vapor initially forms over the liquid surface, decreasing the driving force for further vaporization. Also, with evaporation of the lighter hydrocarbon molecules, the tendency of the components in the stagnant surface to vaporize decreases. Thus, the degree of saturation in the overall gas space of a tank can be decreased by minimizing liquid surface and vapor space mixing during the filling operation.

Splash loading not only creates droplets which can be entrained in the outgoing effluent and exposes fresh liquid surfaces, but results in mixing of the vapor space as well. This mixing of the vapors disturbs the saturated blanket near the liquid surface, increasing the driving force for further vaporization. Hydrocarbon emissions under splash filling conditions can significantly exceed that calculated by assuming saturation.

Another factor which can affect the quantity of hydrocarbons emitted is the interval between drainage and filling. When a tank is drained and immediately refilled, the air drawn into the tank during draining may be expelled with relatively little hydrocarbon content. In a tank allowed to sit after draining, the air drawn into the vapor space becomes saturated with hydrocarbons, thus, increasing pressure (and emissions) and resulting in the maximum loss of vapor during refilling.

Another operational procedure which may increase losses is the small sequential withdrawals of gasoline from a storage tank over a period of several days rather than one continuous large withdrawal. After a small withdrawal, the post-transfer emissions caused by evaporation tend to be high in hydrocarbons since little air is ingested during the withdrawal. After a large withdrawal, the initial post transfer emissions are low in hydrocarbons since large amounts of air are ingested during the withdrawal.

3. Miscellaneous Losses

Miscellaneous losses have been found to be highly variable. These losses include spillage, liquid and vapor leakage and operational losses which occur when opening tank hatches for visual inspection or measuring liquid levels with dip sticks. Leakage can occur and has been observed at dry breaks, pressure vacuum valves, hatches, manholes, pump seals, shut-off valves and piping joints. It has been visually observed that some spillage (on the order of half liter) occurs when connecting and disconnecting transfer lines. Visible liquid leakage at dry breaks (few milliliters of gasoline) was observed from the connections after transfer. Opening of hatches of an empty truck to verify that they have received all the gasoline expected.

B. Control Concepts

When estimating emissions from an operation it is imperative that knowledge of the control concepts and how they effect the emissions are available. The controls that were used as determined by the survey are discussed in this section.

1. Breathing Losses

Storage tanks are subject to evaporation or standing losses due to volatility of the material stored, type and condition of the tank and its appendages and prevailing meteorological conditions. The simplest methods for reducing these venting losses are to (1) inspect and repair leaks in the tank and fittings, (2) paint the tank with white paint where possible, (3) assure that vent valves do not leak and (4) set the pressure and vacuum relief settings to minimize breathing. The broader the band for the vent valve settings, the lower will be the breathing losses.

Another method for preventing vapor loss is to install vapor recovery equipment at the vent valve. For vapor recovery, the vented vapor must be able to be condensed and recycled to the tank or be collected and regenerated. For prevention of pollution only, the vapors can be combusted or collected and disposed of in some approved manner.

2. Working Losses

Excluding spillage, the two major sources of loss of gasoline vapor during transfer are 1) venting to the atmosphere the volume of gases--air and hydrocarbons--displaced by the entering liquid and 2) filling in a manner which creates turbulence which results in increased vaporization rates and liquid droplet entrainment in the vapor space.

The most common current methods of reducing working losses are to use submerged filling for the loading of gasoline and to install a vapor balance system between the vapor spaces of the tanks connected during the gasoline transfer.

a. Submerged Fill

Submerged fill is the introduction of liquid gasoline into the tank being filled with the transfer line outlet being below the liquid surface. This is compared to splash loading, where the transfer line outlet is at the top of the tank. Submerged filling minimizes droplet entrainment, added vaporization and turbulence. If a fill port is located at the tank top, submerged fill is accomplished by either extending the nozzle (commonly referred to as stingers) or permanently attaching to the fill port a pipe extending to within 6 inches (15 cm) of the tank bottom. This permanent installation is commonly referred to as a drop tube.

Aboveground storage tanks normally include submerged fill. Submerged fill for underground storage tanks can be accomplished by attaching a pipe to the fill port. These installations were common on underground tanks in surveyed areas.

Bottom loaded trucks by definition include submerged filling. Top loaded trucks utilize an extension such as a pipe or flexible hose on the loading arm, or a pipe can be permanently attached to the trucks.

Submerged filling of customer tanks can be accomplished with either nozzle extension or a permanently attached drop tube. Some difficulties have occurred with the installation and use of permanent drop tubes. One problem is "spit back." "Spit back" is the return flow and spillage of gasoline at the fill port during transfer. This appears to be primarily related to the smaller fill port and drop tube sizes in customer tanks, compared to service station tanks, and the lack of a coupling at the fill port interface. Use of a nozzle extension with or without a permanently installed drop tube or a coupling should solve the "spit back" problem.

b. Balance System

Probably the most common vapor recovery system currently in use is the vapor balance system. Efficiency is good for the control of working losses, but not significant in controlling breathing losses. A pipeline between the vapor spaces of the truck and storage tanks essentially creates a closed system permitting the vapor spaces of the tank being filled and the tank being emptied to balance with each other. The net effect of the system is to transfer vapor displaced by liquid into the tank in which draining of the liquid creates additional vapor space. This prevents the compression and expansion of vapor spaces which would otherwise occur in a filling operation. If a system is leak tight, very little or no air is drawn into the system and venting dur to compression also is reduced substantially. The system is applicable to underground and aboveground storage facilities equipped with either bottom or top loading, and are applicable to both incoming and outgoing transfers.

c. Secondary Control Systems

Secondary control systems, such as refrigeration, oxidation, adsorption, etc., were found in only one of the study areas, San Diego. Many systems had been initially installed but only one such system was operating. This vapor recovery system employed a refrigeration unit to reduce pressure in the storage tanks and thereby to minimize venting. In this system, vapors were drawn from the storage tanks by a blower, passed over cooling coils in the refrigeration unit and exhausted back to the storage tanks through an insulated return line. The system made no effort to condense vapors but was designed strictly to maintain a constant temperature in the storage tanks (in this case $60^{o}F$) and thereby maintain a pressure below the venting level.

3. Efficiencies

For determination of the emission quantities, efficiencies corresponding to the described control concepts had to be generated. These were based upon test results, emission factors and literature. Submerged fill resulted in an emission reduction of 58.6% from transfer losses based upon emission factors used. The balance system efficiency was estimated at 90% based upon actual test results. The efficiency used for the secondary system was also 90% based upon test data. This perhaps is low but only one such system was in operation out of the nearly four hundred bulk plants surveyed and it was felt that this error was very minor.

C. Development of Emission Factors

The actual hydrocarbon emission factors were determined by using emission formulas, such as API formulas for storage tank losses, and data on typical bulk plants, as described by the inventories. For example, the API equation for the breathing losses from fixed roof tanks is:

$$L = 2.21 \times 10^{-4} M \left(\frac{P}{14.7 - P}\right)^{0.68} D^{1.73} H^{0.51} T^{0.50} F_p \, CK$$

Where:

L = Fixed roof breathing loss (lb/day)

M = Molecular weight of vapors lost (lb/lb mole)

P = True vapor pressure of liquid at bulk liquid temperature (psia)

D = Tank diameter (ft)

H = Average vapor space height (ft)

T = Average daily ambient temperature change (°F)

F_p = Paint factor (dimensionless)

C = Adjustment factor for small diameter tanks (dimensionless)

K = Adjustment factor dependent on product stored (Dimensionless = 1 for gasoline)

Typical values for bulk plants in the study areas were as follows:

M = 66

P = 42,800 newtons/sq meter (6.2 psia, for RVP-10 gasoline at 70°F)

D = 3.2 meter (10.5 ft survey average)

H = 4.0 meter (13 feet, 1/2 survey average tank height)

T = 8.3°C (15°F)

F_p = 1.24 for white roof and specular aluminum shell in poor condition, condition based on survey observations)

C = 0.55

By substituting these values into the equation, an emission factor of 6.7 lb/day/tank was obtained. In many of the counties surveyed, actual throughput data was not obtained for each bulk plant location. Since the purpose of the emission inventory was to develop total emissions from bulk plants in the study regions, an average throughput for the particular county or region was determined from the survey data and applied to all bulk-plant operations within the study areas.

The emission factors derived for the estimating procedures were:

Fixed Roof Storage Tanks:	Breathing Loss	6.7	lb/tank/day
	Working Loss	9.7	lb/1000 gal.
Truck Loading Losses:	Splash Fill	14.0	lb/1000 gal.
	Submerged Fill	5.8	lb/1000 gal.
Miscellaneous Losses:		3.2	lb/1000 gal.

D. Emission Estimates

Emission estimates based upon the bulk plant inventories were generated for all regions. As an example, emission estimates for the bulk plants in the Houston/Galveston area were calculated for uncontrolled sources, for emissions from bulk plants with current vapor recovery controls, and emissions from bulk plants with potential control under the existing Texas SIP regulations. For estimating uncontrolled emissions, it was assumed that no vapor recovery equipment was installed and that all tank fillings and transfers to account trucks were by splash filling. This would amount to the worst case emissions. For the purposes of these calculations, the average annual throughput of gasoline through each bulk plant was 2,203,000 gal (8,338,000.1), based upon the PES bulk plant sample. Also for the purposes of these calculations, seventy bulk plants were assumed to be operating in the area.

The uncontrolled emissions from the bulk plants in the Houston/Galveston area were:

Breathing losses from aboveground tanks -
236 tons/year (214 metric tons/year)

Working losses from all bulk plant storage tanks -
737 tons/year (tt8 metric tons/year)

Transfer losses from filling account trucks -
1063 tons/year (964 metric tons/year)

Transfer losses from filling account storage tanks -
1063 tons/year (964 metric tons/year)

Miscellaneous losses -
243 tons/year (220 metric tons/year)

Total uncontrolled hydrocarbon emissions -
3342 tons/year (3031 metric tons/year)

The emission factors used for these emission estimates were the same as those listed in the previous section.

To determine current emissions from bulk plants, data on Phase I and Phase II controls* installed were obtained from the PES bulk plant survey. From this data, it was found that 75% of all the bulk plants had installed Phase I vapor recovery. Phase II controls were installed at 36% of all the bulk plants. Vapor recovery had been installed on at least one truck at 68% of the facilities. For calculation purposes, it was assumed, since most bulk plants had one truck with vapor recovery and one without, that the deliveries which went to exempt accounts, i.e., farm accounts and tanks less than 2,000 gal (7,600 l.), were made with the delivery truck which had no vapor recovery. From the PES survey, the average bulk plant delivered 50% of its gasoline -- 67% of its accounts -- to exempt accounts. An efficiency of 90% for the Phase I and Phase II controls was used.

---

*Definition of Phase I and Phase II controls found in Table II

The hydrocarbon emission estimates for the bulk plants in the Houston/Galveston area incorporating current vapor recovery control installations were:

Breathing losses from aboveground tanks -
236 tons/year (214 metric tons/year)

Working losses from all bulk plant storage tanks -
239 tons/year (217 metric tons/year)

Transfer losses from filling account trucks -
791 tons/year (718 metric tons/year)

Transfer losses from filling account's storage tanks -
638 tons/year (579 metric tons/year)

Miscellaneous losses -
243 tons/year (1948 metric tons/year)

Total hydrocarbon emissions incorporating current control practices -
2148 tons/year (1948 metric tons/year)

Under current control practices, a 67.5% reduction in working losses, a 25.6% reduction in transfer losses involving account trucks and a 40% reduction in transfer losses involving account tanks served have been accomplished. This is an overall hydrocarbon emission reduction of 35.7% representing 1,194 tons/year (1,083 metric tons/year) from all bulk plant emission sources.

To determine the amount of potential reduction of the hydrocarbon emissions, the vapor recovery and emission controls as outlined in the Texas SIP regulations were extrapolated for the gasoline throughput used above. This would mean that Phase I controls would be installed on all bulk plants, Phase II controls on the racks would be used on all non-exempt deliveries and submerged fill pipes would be installed on all non-exempt tanks. The SIP regulations, as written, do not require any controls to limit storage tank breathing losses and miscellaneous losses (i.e., spillage) so these emissions levels do not vary.

The hydrocarbon emission estimates for the bulk plants in the Houston/Galveston area incorporating potential vapor recovery controls were:

Breathing losses from aboveground tanks -
236 tons/year (214 metric tons/year)

Working losses from all bulk plant storage tanks -
74 tons/year (67 metric tons/year)

Transfer losses from filling account trucks -
585 tons/year (530 metric tons/year)

Transfer losses from filling account's storage tanks -
585 tons/year (530 metric tons/year)

Miscellaneous losses -
243 tons/year (220 metric tons/year)

Total hydrocarbon emissions incorporating potential emission controls under Texas SIP regulations -
1723 tons/year (1562 metric tons/year)

Under potential control strategies presented in the Texas SIP regulations, a 90% reduction in hydrocarbon working losses from bulk plant storage tanks and a 45% reduction of transfer losses to both account trucks and account tankage would be experienced.

This would yield an overall bulk plant emissions reduction of 48.5% or 1620 tons/year (1469 metric tons/year). If it is assumed that all deliveries made from the bulk plant would require Phase II controls, not just non-exempt deliveries, a further reduction in bulk plant emissions would occur. The overall bulk plant hydrocarbon emissions would then be reduced to 1244 tons/year (1128 metric tons/year). This would then indicate an overall emissions reduction of 63% or 2098 tons/year (1903 metric tons/year).

Not only were emission estimates supplied to show the effect of control strategies, but also to illustrate how proposed or possible regulatory strategies would effect the emission quantities. An example of this is shown in Table V, illustrating how potential regulatory actions would effect emissions from bulk plants in the Houston/Galveston area.

Table V. SUMMARY OF DECREASE IN EMISSIONS FROM BULK PLANTS IN HOUSTON/GALVESTON AREA AS FACILITIES COMPLY WITH HYDROCARBON VAPOR RECOVERY REGULATIONS

Facility Description	Number of Plants Affected	EMISSION ESTIMATE											
		TOTAL		Breathing Losses From Above Ground Tanks		Working Losses from All Storage Tanks		Transfer Losses To				Miscellaneous Losses	
								Account Trucks		Account Tanks			
		T/Yr[b]	MT/Yr[c]	T/Yr	MT/Yr	T/Yr	MT/Yr	T/Yr	MT/yr	T/Yr	MT/yr	T/Yr	MT/Yr
Vapor recovery on all bulk plant operations and account tanks	70	765 1723	693 1563	236 236	214 214	74 74	67 67	106 585[a]	96 531	106 585	96 531	243 243	220 220
Total compliance with current, approved SIP Regulations.	70												
Total Gasoline Throughput ≥20,000 Gal/Mo.	70	1723	1563	236	214	74	67	585	531	585	531	243	220
Total Gasoline Throughput ≥4,000 Gal/Day	54	2095	1900	236	214	226	206	695	630	695	630	243	220
Throughput to Non-Exempt Accounts ≥2,000 Gal/Day	36	2499	2266	236	214	392	356	814	738	814	738	243	220
Throughput to Non-Exempt Accounts ≥2,000 Gal/Day or Total Gasoline Throughput ≥4,000 Gal/Day	34	2566	2326	236	214	419	380	834	756	834	756	243	220
Total Gasoline Throughput ≥8,000 Gal/Day	29	2678	2428	236	214	465	422	867	786	867	786	243	220
Total Gasoline Throughput ≥8,000 Gal/Day or Throughput to Non-Exempt Accounts ≥2,000 Gal/Day	20	2872	2604	236	214	545	494	924	838	924	838	243	220
Total Gasoline Throughput ≥12,000 Gal/Day	11	3084	2796	236	214	631	572	987	895	987	895	243	220
Total Gasoline Throughput ≥12,000 Gal/Day or Throughput to Non-Exempt Accounts ≥2,000 Gal/Day	9	3132	2840	236	214	651	590	1001	908	1001	908	243	220
Total Gasoline Throughput ≥20,000 Gal/Day[d]	2	3294	2986	236	214	717	650	1049	951	1049	951	243	220
No Plants in Compliance	0	3342	3030	236	214	737	668	1063	964	1063	964	243	220

[a] It is assumed that deliveries to exempt accounts are done with trucks without vapor recovery

[b] T/Yr = Tons/Years

[c] MT/Yr = Metric Tons/Year

[d] Current Texas State Regulation V incorporates this exemption

V. Conclusions

Based on the inventories completed in the five study areas, it can be concluded that data on small bulk plants in other areas of the county are very limited. Specific bulk plant inventories would be necessary in these areas. Even if an inventory exists, it may be quickly out-dated because of the rapid changes in current gasoline marketing trends.

The direct inquiry approach to obtaining inventory data was very successful especially for obtaining information on control concepts currently employed in the field. Enough information to successfully complete the study objectives was gathered without having to resort to Form 114 letters.

Finally, the current hydrocarbon emission levels from small bulk plants can vary considerably from region to region. (For example, hydrocarbon emissions from the seventy bulk plants in the Houston/Galveston area are currently 2148 tons/year while the hydrocarbon emissions from the fifty-six bulk plants in the Baltimore and National Capital AQCR's totalled only 725 tons/year). The variation is due mostly to the number of operating bulk plants, the accompanying throughput, and the controls currently being used.

Bibliography

R.J. Bryan, M.M. Yamada and R.L. Norton. "Effects of Stage I Vapor Recovery Regulations on Small Bulk Plants and on Air Quality in the Washington, D.C., Baltimore, Maryland and Houston/Galveston, Texas Areas." Pacific Environmental Services, Inc. under EPA Contract No. 68-01-3156, Task No. 28, March 1977.

R.J. Bryan, R.L. Norton and P.S. Bakshi. "Compliance Analysis of Small Bulk Plants." Pacific Environmental Services, Inc. under EPA Contract No. 68-01-3156, Task No. 17, October 1976.

R.J. Bryan, W.O. Jacobson and R.R. Sakaida. "Study of Gasoline Vapor Emission Controls at Small Bulk Plants." Pacific Environmental Services, Inc. under EPA Contract No. 68-02-3156, Task No. 15, October 1976.

"Revision of Evaporative Hydrocarbon Emission Factors." Radian Draft Report No. 100-086-01, June 15, 1976.

Applicable SIP Regulations on Gasoline Transfer Vapor Control:

40 CFR52 - Subpart F - California	52.255
40 CFR52 - Subpart G - Colorado	52.336
40 CFR52 - Subpart V - Maryland	52.1101
40 CFR52 - Subpart SS - Texas	52.2285 52-2286
40 CFR52 - Subpart VV - Virginia	

APPENDIX A

SMALL BULK PLANT EVALUATION

SMALL BULK PLANT EVALUATION

1. Owner Operator ______________________

Address ______________________

____

Contact ______________________ Phone (   ) __________

2a. Gasoline throughput __________ gallons/month

2b. Grades of gasoline ______________________

3a. Other products sold ______________________

3b. Percentage of business selling gasoline __________

4. Underground tanks - number ______________________

Capacities ______________________

5. Aboveground tanks - number __________

Capacities ______________________

6. Top loading ______________________

Bottom loading ______________________

Submerged fill ______________________

7. Supply vehicles owned by ______________________

Number ______________________

Capacity ______________________

Frequency of delivery ______________________

8. Delivery vehicles owned by ______________________

Number __________

Capacity __________

Time to fill __________

9. Fugitive emissions ______________________

10. Vapor Recovery, Deliver Vehicle

Date installed __________ by whom ___________

Cost __________

Bottom or Top Load __________

Operating Problems __________

11. Vapor Recovery Storage Tank/incoming loads

Date installed ___________ by whom __________

Cost ______________

Operating Problems ____________

12. Vapor Recovery, Storage Tank/Loading Rack (Delivery)

Installed ________________ by whom ____________

Installation Cost __________, Operating Cost _______________

Maintenance Cost ___________

Operating Problems _____________

13. Vapor Recovery, Delivery Vehicle

Installed _________________ by whom ___________

Installation Cost _____________ Operating Cost _____________

Maintenance Cost ______________

Operating Problems ____________

14. Percent Deliveries to Exempt Customers ____________

Type of Exemption: Agricultural _________________

Small Tanks ______________ Size ________

Other ____________________

Of Non-exempt customers, what vapor control techniques are being used ______________________________

15. Assume vapor recovery will initially cost $20,000 and operating costs increase 20%.

a) Would you stay in business

b) Could you obtain loan ______Down payment required _________

c) Comments

Repeat for $10,000 ____________$30,000______________________

16. What could you sell your trucks, facility, accounts receivable and good will for $_______________

What did you originally invest $______________

17. Present margin ____________

Annual sales $____________ Gallons _________________

Profit $_______________

Debts $________________

18. Debt-equity or debt-total assets ratio _______________________

Rate of return on total assets or net worth ___________________

Break even point ______________________________

Assessed valuation ______________________________

19. Comments - Closures, Competitors, bottom loading, etc.

P-193

AN ORGANIC SPECIE EMISSION INVENTORY FOR STATIONARY SOURCES IN THE LOS ANGELES AREA - METHODOLOGY

By

Harold J. Taback, KVB, Inc.
Tim W. Sonnichsen, KVB, Inc.
Nicholas Brunetz, KVB, Inc.
Joan L. Stredler, Abacus Programming Corp.

For

EMISSION INVENTORY/FACTOR WORKSHOP
September 13-15, 1977
Raleigh, NC

TABLE OF CONTENTS

Section		Page No.
1.0	INTRODUCTION	1
2.0	INVENTORY DATA PROCESSING	4
	2.1 Data Sources	4
	2.2 Data Management	9
3.0	EMISSION PROFILES	13
	3.1 Description	13
	3.2 Methodology	14
4.0	EMISSION FACTORS	18
	4.1 Point Sources	18
	4.2 Area Sources	23
5.0	FIELD TESTING	31
	5.1 Field Measurements and Sampling	32
	5.2 Laboratory Analysis	38
	5.3 Quality Control	42
	REFERENCES	43

SECTION 1.0

INTRODUCTION

To provide detailed data on which to model the photochemical formation of atmospheric oxidants and haze and to provide information on which to base comprehensive control strategy, an inventory of gaseous organic emissions from stationary sources was conducted for a district in California known as the South Coast Air Basin. This region includes portions of Santa Barbara, Ventura, Los Angeles, Orange, Riverside, and San Bernardino Counties. Unlike most organic emissions inventories in the past, this study included the development of emission profiles, i.e., a breakdown of the individual organic species which contributed at least 1% of the total organic emissions from each source. From one to 30 different species were identifed in the emission profiles which were developed for 200 sources by a comprehensive field sampling and laboratory GC-MS analysis program.

The inventory accounted for all known stationary source organic emissions including major and minor point sources and area sources (oil production fields, architectural coatings, domestic solvent usage, etc.).* The inventory was prepared in the EPA's Emission Inventory Subsystem (EIS) format. All sources were located by Universal Transverse Mercator (UTM) coordinates.

A three-phase approach wastaken in conducting the program. First, a preliminary inventory of total organics (without specific species) was prepared to identify the major sources and to determine the distribution of emissions among the various source types. Next, a field test program was conducted to characterize emissions from sources selected on the basis of the preliminary findings, emphasizing those source types comprising the greater amount of the emissions. Test results were augmented by questionnaire responses and literature data in establishing both emission factors and emission profiles (% composition by weight). In the third phase, a final inventory will be created from the preliminary inventory by the addition of emission profiles and new sources (especially area sources) and the updating of emission factors.

---

*A major point source was defined as any emission source belonging to a point with total organic emissions of more than 25 tons per year.

To appreciate the approach taken in this inventory, it is important to understand the potential magnitude of the task and the budget which was allocated for the program. There were over 50,000 active permits covering the sources in the various county districts. The final inventory will account for over 8,000 major point sources of organic emissions plus minor point sources (which include gasoline stations) and area sources. The total effort budgeted for this program, including field testing, laboratory analyses, other data collecting, data analyses and processing, as well as the overall program management, was only eight people for one year plus expenses (computer, travel, equipment, etc.). Thus, maximum use was made of existing information. The new research performed on the program was to:

1. Provide information where none existed
2. Check the validity of existing data, and
3. Update existing data to reflect current trends.

The characterization of refinery emissions was an example of how judiciously the test program was designed. In the late 1950's the Los Angeles APCD and EPA spent an 8-10 person effort for more than two years to characterize total hydrocarbon emissions from the refineries in the Basin. The EPA is currently sponsoring a program to measure refinery emissions alone with a budget that is three times greater than the one available on this program in which all of the emissions in one of the largest industrial areas of the country has to be characterized. This program afforded a total refinery testing effort of five weeks with a crew of four. Thus testing was primarily directed at obtaining emission profile data and checking the emission factors developed on the 1950's project.

The inventory was conducted by KVB, Inc. under sponsorship of the California Air Resources Board (ARB)* as part of a total program which also included a study of control systems and a 10 year projection of emissions. Preliminary inventory data, EIS format data and technical advice on emissions and data processing were received from the South Coast Air Quality Management District (SCAQMD) and the APCD's of Ventura and Santa Barbara Counties. GC/MS analyses of emission samples and advice on the development of the field sampling train were provided by Analytical Research Laboratories, Inc. (ARLI) of Monrovia, CA, Mr. M. L. Moberg, President and Chief Chemist. Data quality and evaluation was performed by EcoScience Systems, Inc. of Riverside, CA, Dr. James N. Pitts, Jr., President and Principal Consultant. Data management and computer programming were provided by Abacus Programming Corporation of Santa Monica, CA, Mr. Calvin Jackson, Vice President and Director of Production. The Western Oil and Gas Association provided guidance and assistance in the petroleum industry aspects of the program. A special measurement of refinery emissions using ambient testing and diffusion modeling techniques was performed by Aerovironment, Inc. of Pasadena, CA, Mr. Ivar Tombach, Vice President and Program Director.

At this writing the final emission inventory had not been compiled pending the completion of EIS data entry and checkout by the SCAQMD and the APCD's. In this paper the methods used to collect, formulate and process the inventory data are presented. It is estimated that the inventory itself will be published by the end of 1977 along with a comprehensive engineering report.

---

*Dr. John R. Holmes, Research Division, Chief, and Mr. Jack Paskind, Research Project Officer.

SECTION 2.0

INVENTORY DATA PROCESSING

2.1 DATA SOURCES

The data used in this organic emission inventory were obtained from the following sources:

1. Various government agency files
2. Field testing
3. Questionnaires
4. Literature
5. Engineering analyses
6. Personal contacts with government and industry personnel.

All county enforcement agencies were in the process of a total recompilation of their permit files using the EPA's EIS/P&R* (Ref. 1) format (referred to as EIS hereafter) during the period of this inventory. The computerized permit file from Los Angeles County and the permit files from the other counties were used to obtain data for the preliminary inventory. It was planned that the final inventory would be compiled using the new EIS data base for the major point sources as soon as data entry was completed and checked for all counties in the inventory. The following key data were contained in the EIS data base:

1. Plant name, address, ID No., etc.
2. Standard Industrial Code (SIC)
3. Source Classification Codes (SCC)
4. UTM Coordinates
5. Stack Height
6. Pollutant Identification
7. Emission Factor
8. Throughput Rates

---

*Emission Inventory Subsystems/Permit and Registration

9. Estimated emissions
10. Seasonal variations
11. Operating period (hr/day, day/week, week/yr)

For minor sources in LA County, the original permit file was used. Also a computer tape file of gasoline station locations in LA County was received from the SC AQMD. Both of these files had location coordinates on a one mile square grid basis. The ARB provided an algorithm for converting the one-mile grid to UTM coordinates (Ref. 2).

The ARB also provided a tape file of population by UTM coordinates which was used to distribute population related area source emissions.

Field test data were used to formulate emission profiles and to develop emission factors for new sources or check those factors on sources already characterized by the districts or the EPA in AP-42 (Ref. 3).

Questionnaires were received from approximately 100 industrial sources with comprehensive data on their solvent and fuel usage. Data received were used to develop emission profiles and to check values contained in the district files.

There was a great deal of activity in the area of organic emission assessment by other agencies and contractors. A list of those programs which provided valuable data forthis inventory are summarized in Table 1. Excellent cooperation and data exchange were maintained with those contractors and agencies listed.

Other sources of information included personal contacts with various industry associations (dry cleaning, refinery, asphalt, printing, etc.) and government agencies (especially the ARB, California Division of Oil and Gas, EPA Office of Air Quality Planning and Standards in Durham, EPA Region 9, local air pollution districts and the Southern California Association of Governments, SCAG).

From data received from the above sources, comprehensive analyses were conducted to derive emission profiles in a form compatible with the inventory format. Analyses of test data from this and related programs listed in Table 1 were performed to create or evaluate existing emission factors.

TABLE 1. RELATED STUDIES ON ORGANIC COMPOUND EMISSIONS

Project Title	Scope	Sponsor*	Contractor	Status (as of Mid 1977)
Air Quality Impacts of Outer Continental Shelf Oil Development in the Santa Barbara Channel	Assess the impacts of OCS development on the environment	OPR	OPR Staff & ERT, Inc.	Final Report Draft issued March 1977
Fugitive Emissions from Oil Field Production Operations	Determine emission factors on a component basis for onshore and offshore facilities	API	Rockwell Air Monitoring Center	Work plan being developed
Assessment of the Environmental Effluents from Oil Refining	Determine validity of refinery emission factors currently used in AP-42	EPA	Radian, Inc.	Tests are currently being conducted in second refinery
Emissions from Ships and Shipping Operation including Transfer of Oil	Determine emissions from shipping operations in the SCAB	ARB	Scott Research Laboratory	Work plan being developed
Hydrocarbon Emissions from Floating Roof Petroleum Tanks	Determine validity of AP 2517	WOGA	Engineering Science, Inc.	Final Report released Jan. 1977
Hydrocarbon Emissions from Fixed Roof Tanks	Assess the validity of AP 2518	WOGA	Engineering Science, Inc.	Final Report released July, 1977
Hydrocarbon Emissions from Tanker Loading Operations	Determine HC emissions resulting from crude oil loading off Ventura and Santa Barbara counties	WOGA	Chevron Research, Inc.	Final Report originally scheduled for May 1977

TABLE 1. RELATED STUDIES ON ORGANIC COMPOUND EMISSIONS (Continued)

Project Title	Scope	Sponsor*	Contractor	Status (as of Mid 1977)
Floating Roof Tank Metallic Sealing Ring Emission Test Program	Determine effects of wind, ring quality, gap size and secondary seals on HC emissions	WOGA	Chicago Bridge and Iron	Final Report issued March 1977
Organic Compound Emissions From Natural Sources	Determine natural emission rates from forest vegetation	EPA	Washington State University	Final draft completed
Emission Factors from Burning Agricultural Wastes Collected in California	Determine emission factors from burning 31 field and orchard crops	ARB	UCR Statewide Air Pollution Research Center	Final Report, January 1977
ORGSOL Regulation Study Group Architectural Coatings Survey	Determine potential reduction of organic emission using H_2O borne paints	ARB	ARB Staff	Staff report issued June 1977
A Methodology for Reactive Organic Gas Emissions: Assessment of Pesticide Usage in California	Determine HC emissions from pesticide applications	ARB	ARB Staff	Report due August 1977
Gasoline Marketing Vapor Recovery System Development	Determine test procedures to assess the effectiveness of vapor recovery techniques applied to petroleum marketing	SDAPCD	SDAPCD	Test continuing

Continued

TABLE 1. RELATED STUDIES ON ORGANIC COMPOUND EMISSIONS (Continued)

Project Title	Scope	Sponsor*	Contractor	Status (as of Mid 1977)
Measurement of Atmospheric Organic Emission from Natural Sources	Determine HC emission factors from asphalt operations and landfills	EPA	Midwest Research Institute	Preliminary tests underway
Control of Volatile Organic Emissions for Existing Stationary Source	Preparation of documents for control of organic emissions	EPA	EPA Air Program Staff	Volume 1 issued November 1976. Future volumes to be released late 1977.

*Abbreviation code: OPR = California Governor's Office of Planning and Research
API = American Petroleum Institute
EPA = U.S. Environmental Protection Agency
ARB = California Air Resources Board
WOGA = Western Oil & Gas Association
SDAPCD = San Diego Air Pollution Control District

2.2 DATA MANAGEMENT

The data to be processed as part of the final organic emission included:

1. EIS data for major point sources for SCAQMD
2. Minor point source data from the SCAQMD (Metro Zone)
3. Gasoline station data for SCAQMD (Metro Zone)
4. EIS data for Ventura and Santa Barbara County (major and minor sources including gasoline stations)
5. Petroleum production field
6. Additional area data for sources such as forests, landfills, architectural coating, domestic solvent use, etc.
7. Emission profiles
8. Population distribution by one kilometer grid
9. Emission factor adjustments to EIS data

The available EIS data processing software was incorporated for processing the EIS data. In this system individual sources could be modified, added or deleted. KVB added a feature which also permitted the data to be modified by SCC number. For example, the emissions in the EIS data base from certain fixed roof tanks (identified by a specific SCC number) were believed to be too high based on recent test data. The emissions from those tanks were modified by one correction factor applied to all the emissions of that specific SCC number.

The profile data was organized with SCC number as the key. The specific organic specie emissions for any source were determined by factoring the total source emissions by the profile of specie weight percentages.

In describing organic emissions, the point source data were a minor portion of the emissions, whereas natural emissions, architectural surface coatings and gasoline marketing constitute the major portion of the emissions. Since a standard format was not yet available for describing emissions not meeting the EIS point source criteria, KVB choose to develop an area source data base for this purpose. The format was designed to allow description of emissions by their one kilometer grid location and process (or activity).

Gasoline marketing data for this data base were acquired in three different ways. In Los Angeles County, information concerning 10,000 stations in the Basin was computerized; however, individual station through-puts were missing. KVB chose to take the total sales for Los Angeles County and apportion the through-put by the total storage tank volume at each station. For Ventura County the gas station data were included in the EIS file. For consistency, KVB chose to take these EIS data and format them as the Los Angeles County data with the gas station locations and through-puts retained. KVB assigned new emission factors to the data. For the remaining counties the gas station emissions were apportioned by residential area based on the total county sales. These gas station data were formatted in the KVB area source format.

Since the EIS point source data base did not contain the organic emissions for minor point sources under permit in L.A. County (Metro Zone), these data were acquired from Metro Zone's permit files and formatted in the KVB area source format. Data on the emissions from minor point sources not under permit were also obtained and included in the KVB area source data base.

Finally the KVB area source data base contained data from all area sources identified by the KVB engineers. These emission sources included waste disposal, petroleum operation other than refining, domestic and agricultural sources, geogenic sources and natural emissions.

All sources in the inventory were given an SCC number which was occasionally qualified by the SIC number. (SCC numbers for area sources were created after consultation with ARB personnel.) A file was created with all information relative to these SCC numbers, the emission correction factors to be applied to all sources with the given SCC/SIC number, the profile key to identify the profile for this source type, the relevant ARB application category, and summer or winter differentials to be used to alter emissions seasonally if warranted by the source type. This SCC file was used as the major system link between sources and their profiles.

Within each ARB application category only unique profiles were identified. The profile records contained information concerning the method of determining the profile and estimated error. In addition, each profile contained the SAROAD code and percent by weight of each specie in the profile. Where the SAROAD coding was not comprehensive enough, KVB and their subcontractor, ARLI, added SAROAD codes in a logical manner. Since SAROAD codes were the only specie identifier in the profile data base, a separate tabular file was created to contain SAROAD codes, species name, molecular weights and ARB reactivity class.

From the data files used in this inventory nine reports were to be produced. They included:

1. A Total Organic Emission Report containing:
    a. Source information (county, APCD Point ID No., SSC No., SIC No.)
    b. Total organic emissions, ton/year
    c. Summer emissions, ton/day, broken down into weekday emissions and weekend emissions
    d. Winter emissions, ton/day, broken down into weekday emissions and weekend emissions
    e. Emission profile key which will relate to an emissions species breakdown in Item 2 below.

    These data were reported in two sorted orders:

    a. According to the ARB application categories and including point and area sources (Report #1)
    b. According to location in 10 Km UTM grid squares and including point and area sources (Report #2)

    Two plant identification indexes were also provided as in the preliminary inventory, one in alphabetical order by company name (Report #3) and one by point ID no. (Report #4).

2. An Emission Profile Listing which lists each organic specie (by name and code no.) emitted by a particular source or source type, the reactivity class (according to the ARB's 3-class system) of that specie, and the percent by weight of the total emitted hydrocarbons that the specie contributes (Report #5).

3. An Emission Summary consisting of the following data for each 1 Km grid square in the Basin (Report #6):
    a. Total organic emissions, ton/year
    b. Individual specie emissions by code no., lb/year
    c. Emissions for each reactivity class: I, II, and III, ton/year
4. An Individual Organic Specie Report showing the emission of each specie broken down by ARB Application Categories (Report #7).
5. An SCC report listing the profile keys, application and emission correction factors for all SCC codes encountered in the source files.

    These data were reported in two sorted orders:

    a. By SCC code (Report #8)
    b. By profile key in order to reference all SCC codes attributed to a given profile (Report #9).

SECTION 3.0

EMISSION PROFILES

3.1 DESCRIPTION

A unique aspect of the current program was the development of emission profiles, the identification of the organic compound species represented by the total hydrocarbon emission rates currently given in emission measurements. Only one other study (Ref. 4) had previously attempted a breakdown into generic classes. That was done primarily for the purpose of dividing emissions into reactivity classes. The results of that previous study have been widely used in the Basin.

A primary objective of this program was to identify the organic compound emissions for each stationary source type in the Basin and develop a data management system capable of applying this information to the total hydrocarbon emissions in order to calculate the emissions of the individual organic compounds. Thus an emission profile was formulated for each Source Classification Code (SCC) emitting organic compound species in the Basin. Both point and area sources were included. In certain instances a further breakdown was made into individual industries identified by Standard Industrial Codes (SIC).

Another objective of this program was to predict future emission trends. Satisfying this objective required emission profiles based on SCC number rather than individual plant profiles based on individual plant characteristics. All plant devices identified by the same SCC and SIC number were given the same emission profile. Conversely, it was important that profiles be truly representative of the device in general. Additional advantages of developing aggregate profiles by SCC number were that: (1) estimations based on larger data samples were more statically reliable than single data samples, (2) the profiles were compatible with the EIS concept by describing devices by the SCC number system, and (3) the volume of profile data was reduced to a more manageable level.

In each profile the organic species were identified by their appropriate SAROAD code and molecular weight. The ARB three class reactivity scheme, which describes reactivity by photochemical smog formation level, was also included. Associated with each emission profile was a subjective estimate of its relative error. Sources of the data for the development of these profiles included KVB test data, KVB source questionnaires, the relevant literature, and private communications with government, industry and academic personnel.

3.2 METHODOLOGY

Two general approaches were used to formulate the emission profiles, one where only one data point was available to characterize many sources and another where multiple data points were available. In cases where a profile was available from only one source and that source was believed to be representative of all such source types in the Basin, then that particular source emission profile was used. An appropriate error estimate was given to reflect the relative confidence level of these data. It was anticipated early in the program that a significant number of source types would fall into this category due to the limited amount of field tests available. Therefore, test locations were carefully selected on the basis of the representative nature of their emissions to all other devices of that particular type. In this way, data from this source could be correctly applied to other non-tested sources. Similarly, questionnaires were submitted to and received from selected solvent users. Follow-ups were made to assure that the data from these large and representative sources were obtained.

Two examples of formulating profiles based on one data point from a selected source are the following. The emission profile typical of residual oil fuel combustion was obtained by (1) recognizing that 95% of all residual oil combustion in the Basin occurs in utility boilers, (2) selecting a boiler that was "typical" of such devices in the Basin and finally (3) conducting a test on this unit. Multiple samples were taken and the profile was based on an average composition. Data from questionnaires were used similarly. One source in the Basin, according to the SCAQMD files, was responsible for 90% of the emissions from adhesive use. A questionnaire was mailed to this source and follow-up contacts were made to assure that information from this source was received. The questionnaire contained a comprehensive breakdown of the composition of the solvent composition and usage which formed the basis for the emission profile.

The second approach used was to develop emission profiles based on data from several sources within a particular source type. This involved (1) acquiring the data, (2) determining the relative magnitudes of each source compared to the total emissions from the source type and finally, (3) forming a composite profile by factoring the data from each source by an appropriate weighing factor. In this manner, emission profiles were developed for individual source types that in actuality represented the average emissions from sources of that category (SCC number).

An example of this approach was the formulation of a profile for "Miscellaneous Organic Storage" in the Basin. There were SCC numbers assigned to storage tanks for gasoline, jet fuel, crude oil, various solvents, etc. This miscellaneous category covered those products not specifically identified. Table 2 presents a summary of the calculation procedures employed to determine this profile. Listed across the top are the various organic products identified and the fraction of the emissions from fixed roof tank storage for each based on information compiled from the SCAQMD file. Listed down the page are the various organic species that have been identified in emissions from these products. The weight percentages of each specie associated with the product is listed in the appropriate column. The weight percentage for asphalt and Stoddard solvent were determined from KVB test data. The adhesive percentages came from questionnaire data. The remainder of the percentages were specified (e.g. 100% for acetone) or estimated based on contacts with industry (e.g. the breakdown of alcohols and ketone). The weight percent of each organic compound in the composite profile was determined by multiplying the weight percents by the appropriate fractions and are listed in the right hand side.

Given in Table 3 are the emission profiles generated for this study for 20 of the major source types in the Basin.

TABLE 2. COMPOSITE PROFILE FOR MISCELLANEOUS PETROLEUM STORAGE

(Fixed Roof Tanks)

Product Stored	[illegible]	Adhesive	Alcohol	Asphalt	Perchloroethylene	Ethylene Dichloride	Formaldehyde	Ketone	Stoddard	Xylene	Others	Composite
Fraction of Emissions	[illegible]	[illegible]	[illegible]	0.079	0.051	0.004	0.004	0.191	0.071	0.057	0.275	
Organic Compounds												16.4
Perchloroethylene					100.0							5.1
Ethylene Dichloride						100.0						0.4
Formaldehyde							100.0					0.4
MEK								65.0				12.4
MIBK								35.0				6.7
Xylene										100.0		5.7
Toluene		5.0									31.0	8.6
Ethane				1.0								0.1
Ethylene				2.0								0.2
Propane				13.0								1.0
n-Butane				18.0								1.4
i-Butane				8.0								0.6
n-Pentane				18.0								1.4
i-Pentane											12.5	3.4
Hexane		90.0		3.0							25.0	8.9
[illegible]				12.0								0.9
Heptane				14.0								1.1
[illegible]				11.0								1.0
[illegible]				1.0					0.8			0.1
[illegible]									27.3			1.9
[illegible]									69.4			4.9
[illegible]									2.4			0.2
Ethyl Acetate		5.0									15.5	4.4
[illegible]											15.5	4.2
Isopropyl Alcohol			40.0									3.4
Ethyl Alcohol			30.0									2.6
[illegible] Alcohol			30.0									2.6

TABLE 3. EMISSION PROFILES

	Profile (% Weight)																	
[illegible]	Residual Oil Combustion	Refinery Gas Combustion	Fiberglass Mfg.	CO Boiler	Fugitive Emissions (Refinery)	Fugitive Emissions (Pet. Production)	Adhesives	Synthetic Dry Cleaning	Petroleum Solvent	Crude Oil Storage	Gasoline Marketing	Crude Tanker Loading	General Primer	General Enamel	General Flexographic	General Rotogravure	Architectural Surface Coating	Natural Forest	Landfills	Miscellaneous Petroleum Storage
[illegible]	11.0	7.6		36.0	28.6	62.0				6.2		10.2			14.4				98.6	
[illegible]		20.9			5.8	17.0	3.9			5.6		3.6			0.7				0.1	0.1
[illegible]																				0.2
[illegible]		18.9			11.5	11.1				17.6	1.8	23.4			0.2				0.1	1.0
[illegible]		17.5			0.1															
[illegible]																			0.2	
[illegible]	16.0	23.1			10.3	4.4				27.1	19.8	26.5							0.2	1.4
[illegible]											1.8									
[illegible]		8.8			7.4	2.9				1.5	6.6	5.4			1.2				0.1	0.6
[illegible]					7.7	0.7				14.6	10.6	7.3							0.1	1.4
[illegible]					7.0	1.1				1.5	29.0	8.0								3.4
[illegible]											6.2									
[illegible]	5.0				3.4		90.0			7.9	2.5	5.6			0.7		20.7			8.9
[illegible]					1.4					9.2	0.6	5.6								1.1
[illegible]					1.0					6.9	0.1	3.0								
[illegible]					0.02							1.0								
[illegible]				13.0	1.5					0.3	8.9									0.9
[illegible]					0.8						2.0									1.0
[illegible]												0.3								0.1
[illegible]					0.6				0.8		1.9									
[illegible]					0.1					0.1	2.1					10.0	20.7			
[illegible]												0.1								
[illegible]					0.5				27.3		0.2									1.9
[illegible]					0.3				69.3											4.9
[illegible]									2.6											0.2
[illegible]					0.3					1.3	0.2									4.2
[illegible]										0.5										
[illegible]					0.1															
[illegible]																		100.0	0.1	
[illegible]													41.0	67.6		51.0				

Continued

TABLE 3. EMISSION PROFILES (Continued)

Chemical Name	Profile (% Weight)																			
	[illegible]	[illegible]	[illegible]	[illegible]	Fugitive Emissions (Refinery)	Fugitive Emissions (Pet. Production)	Adhesives	Synthetic Dry Cleaning	Petroleum Solvent	Crude Oil Storage	Gasoline Marketing	Crude Tanker Loading	General Primer	General Enamel	General Flexographic	General Rotogravure	Architectural Surface Coating	Natural Forest	Landfills	Miscellaneous Petroleum Storage
[illegible]															10.0					
[illegible]													1.0	0.7	3.6	6.0	3.9			
[illegible]													0.8	0.5	2.4		0.6			2.6
[illegible]													2.8	1.9	24.1	6.0	16.4			3.4
[illegible]													4.0	2.8		6.0	1.6			
[illegible]																	0.6			2.6
[illegible]													11.5							
[illegible]																	0.8			
[illegible]																	0.6			
[illegible]							4.1						0.9	0.3						4.4
[illegible]															21.5					
[illegible]													9.5	2.9		8.0	2.5			
[illegible]																	1.3			
[illegible]													0.8	0.3	9.5					
[illegible]																	1.5			
[illegible]																	0.5			
[illegible]																	6.1			
[illegible]	[illegible]	[illegible]		[illegible]																0.4
[illegible]	[illegible]						3.0						7.1	6.3	9.4		3.2			16.4
[illegible]													7.7	6.8	2.0		5.6			12.4
[illegible]																	0.7			
[illegible]													3.1	2.7			0.6			6.7
[illegible]																				0.4
[illegible]							35.0	100.0											0.3	5.1

Continued

TABLE 3. EMISSION PROFILES (Continued)

Chemical Name	Residual Oil Combustion	Refinery Gas Combustion	Fiberglass Mfg.	CO Boiler	Fugitive Emissions (Refinery)	Fugitive Emissions (Pet. Production)	Adhesives	Synthetic Dry Cleaning	Petroleum Solvent	Crude Oil Storage	Gasoline Marketing	Crude Tanker Loading	General Primer	General Enamel	General Flexographic	General Rotogravure	Architectural Surface Coating	Natural Forest	Landfills	Miscellaneous Petroleum Storage
[illegible]													1.0							
Benzene					0.1					0.1	1.1				0.1		*			
Toluene					0.5						2.1		3.9	3.2	0.2		5.2		0.1	8.6
Ethylbenzene																6.0	4.3			
Tri-methyl-benzene											0.3									
[illegible]											0.5									
[illegible]																7.0				
Styrene			100.0																	
Xylenes					0.2						1.6		4.9	4.0			2.6		0.1	5.7
[illegible]											0.1									
TOTAL %	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

SECTION 4.0

EMISSION FACTORS

There has been considerable interest in the development of emission factors that can be employed to estimate emissions from specific sources based upon a knowledge of the pertinent operating characteristics of the source. Such procedures are in common use throughout the country by local control agencies to estimate air pollution emission rates for point and area sources. One of the primary objectives of the ARB organic compound emission study was to critically evaluate these emission factors and to develop new emission factors applicable to the South Coast Air Basin. The following discussion outlines the methodology employed during this analysis. Emission factors for point and area sources were separated as they represent significantly different approaches.

4.1 POINT SOURCES

A comprehensive listing of point source emission factors was found in the EPA publication, "Compilation of Air Pollution Emission Factors" (Ref. 5), hereafter referred to as "AP-42." The SCAQMD had their own emission factors which had been employed in the process of estimating emission rates for industrial point sources contained in the EIS data file. To a certain extent, these emission factors were the same, because frequently SCAQMD data were used as the basis for the development of AP-42 emission factors. In other instances the emission factors differed because the SCAQMD often based their emission factors on their own test data in preference to using AP-42 values.

It was recognized that the emission factors presented in AP-42 were never intended to be totally representative of all such units within a specific source type. Their widespread use, however, has generated several investigations by the EPA and others to broaden their data base and thereby increase their usefulness and accuracy.

A specific objective of this study was to examine the point source emission factors used by the SCAQMD and AP-42. This was done for three reasons. First, much of the data used to generate emission factors for specific source types such as petroleum operations and the combustion of fuels stemmed from studies conducted as far back as the 1950's. Considerable debate has been raised about their continued applicability in view of improved technology, sampling procedures, etc. Second, certain emission factors listed in AP-42 intended for use nationally may not necessarily represent conditions in the Basin. Finally, it was necessary to generate entirely new emission factors where none had existed previously.

Field tests were conducted to provide data to assist in emission factor evaluation and development. In addition, data from several related projects specifically oriented to improving AP-42 emission factors have been incorporated into this analysis. In most cases, these studies had been directed at conditions within the Basin making them directly applicable to the current study.

Comparisons have been made between the emission factors used by the SCAQMD, those contained in AP-42 and those generated in this and related studies. Where the SCAQMD emission factors have been shown to be in error, correction factors have been applied to the emission rates listed in the EIS data system to update these emission estimates. The intent was to have the EIS data system reflect the best and most recent information available. This was a vital part of the improvements incorporated into the final data base.

Since it was the intent of this paper to present general methodology, the analysis used to investigate emission factors for the combustion of fuels and establish correction factors will be discussed in detail as an example of the approach. A similar analysis for petroleum operations including marketing, storage and fugitive emissions will be incorporated into the final report.

It was appropriate to investigate the organic compound emission factors for the combustion of fuels used in the Basin. Emission factors used by the SCAQMD stem from data generated in the 1950's (Ref. 6) and were currently under revision during the study using more up-to-date test data.

AP-42 emission factors represented data accumulated over the last several years and generally had an emission factor rating of A. These emissions factors, however, are still subject to revisions for specific sources.

Emission factors developed during the current program were themselves subject to error due to the broad nature of the test program and the limited number of samples that could be obtained for any one source type. Sources tested were therefore carefully selected so that the tests were as representative as possible of sources of that general type. In addition, a thorough evaluation of the test data was made to assure its accuracy.

The approach for this fuel combustion analysis was, therefore, to compare the emission factors from the three sources (AP-42, SCAQMD and KVB) and thereby ascertain the "best" emission factor. In cases where this emission factor differed from that employed by the SCAQMD, an appropriate correction factor was formulated and applied to the EIS data tape.

Table 4 presents a summary of the sources and emission factors for the combustion of fuels that were evaluated. The table provides a description of the source, the appropriate SCC numbers, the units employed, emission factors listed in AP-42, those used by the SCAQMD, those resulting from field tests conducted during this program and the emission factor used in the final data processing. Also included is the correction factor used to update the EIS data files as described above.

The analysis of the data presented in Table 4 resulted in some interesting conclusions discussed in the following paragraphs.

TABLE 4. ANALYSIS OF EMISSION FACTORS

Combustion of Fuels

Description	Applicable SCC Codes	Units	Emission Factors AP-42	Emission Factors SCAQMD	Emission Factors KVB/ARB	Emission Factor Used in the Current Study	EIS Correction Factor
Residual Oil Power Plants	1-01-004-XX	lb THC/10^3 Gal.	1.0	2.6	0.7	1.0	0.40
Natural Gas Combustion Power Plants	1-01-006-XX	lb THC/10^6 ft^3	1.0	8.8	-	8.8	1.00
Refinery Gas Combustion	3-06-001-02 3-06-001-04	lb THC/10^6 ft^3	30.0	21.9	20.0	21.9	1.00
Natural Gas Industrial	1-02-006-XX	lb THC/10^6 ft^3	3.0	7.0	12	7.0	1.00
CO Boiler	3-06-002-01	lb/10^3 Bbl Feed	200	1.6	1.1	1.6	1.00
Natural Gas IC Engines	2-02-002-02	lb THC/10^6 ft^3	1400	-	1850-11600	1400	NA*

*Added to the data base by KVB

KVB®

P-193

Among the most important of the emission factors investigated was that from the combustion of residual oil in utility boilers. This represented one of the largest uses of fossil fuels in the Basin. The emission factor used by the SCAQMD was approximately 2.5 times that listed in AP-42. For this source type, the results of the KVB test program conducted on a utility boiler firing low sulfur residual oil tended to support the lower figure. Consequently a correction factor was incorporated into the data management program.

Similarly, the SCAQMD emission factor for natural gas combustion in utility boilers was nine times that of AP-42. However, in this case, since the quantity of natural gas used by utilities has decreased dramatically in recent years, a decision was made to forego emissions testing of this source type. Since this represented a relatively insignificant source of organic compounds, the SCAQMD emission factor was not changed.

Refinery gas combustion, on the other hand, represents an important industrial source of organic compounds. In this case, good agreement between the three emission factor sources was obtained and no correction factor was necessary.

Industrial natural gas consumption also represents an extremely large energy use in the Basin. As shown in Table 4, the emission factor used by the SCAQMD was between the AP-42 and KVB emission factors so that again no correction factor appeared warranted.

Emissions from CO boilers treating exhaust gases downstream of an FCC unit were also evaluated. Since the SCAQMD used test results from these units for emissions estimates rather than emission factors, the comparison between SCAQMD values and those obtained in this program has been made for a particular unit. Again, the SCAQMD value appeared to be reasonably close to that obtained during this study and no correction factor was necessary.

Natural gas combustion in IC engines represented another somewhat unique case. At the time of the study, sources of this type were not included in the EIS data file although a preliminary inventory of IC engines in the Basin had been made. This inventory was incorporated into the area source data base for this study. A decision on an appropriate emission factor was somewhat difficult to make. Data presented in AP-42 represented emission factors of 800 hp units much larger than those typically found in the Basin. The results of the tests conducted by KVB on IC engines also resulted in large emission factors however insufficient data were obtained to generalize an emission factor. The AP-42 value was used as it was somewhat conservative, although it was fully recognized that the emission rates from these sources may be higher.

In conclusion, the emission factors for the SCAQMD appeared reasonably good, requiring only one correction factor be applied for the sources listed in the EIS data file. Emission factors employed for natural gas and refinery gas combustion appeared to be adequate for this program. Emission estimates for CO boilers made by the SCAQMD also were verified. There seemed to be additional data required to improve the emission factors used for natural gas IC engines.

4.2 AREA SOURCES

An important aspect of the KVB organic compound inventory was the identification of sources of organic compound emissions not under permit and generally not included or adequately characterized in previous inventories. These sources were grouped as waste disposal, petroleum operations other than refining, domestic and agricultural sources, geogenic sources and natural emissions. Because these were diffuse sources, not concentrated like industrial point sources, they were referred to as area sources. Emission factors for these sources were therefore based on land area, population, land use or other criteria characteristic of the area source.

Table 5 presents a summary of total organic emission estimates from each of the area sources considered. Precise emission rates were difficult to estimate due to the complex nature of each source type. A discussion of inventory and emission factor development for some of the larger area sources is included in subsequent sections.

TABLE 5. EMISSION ESTIMATES FOR AREA SOURCES (TOTAL ORGANICS)

	Tons/Day
Waste Disposal	
Agricultural Burning	2
Sanitary Landfills	930
Petroleum Operations	
Production Operations	60
Marine Terminals	3
Gasoline Marketing	83
Natural Gas Transmission	83
Domestic and Commercial Sources	
Architectural Surface Coatings	93
Solvent Use	31
Fuel Consumption	5
Agricultural	
Natural Emissions	14
Orchard Heaters	3
Animal Wastes	77
Geogenic Sources	
Natural Seeps	11
Forest Emissions	
Natural Emissions	1150
Forest Fires	38
Other Sources	
Dry Cleaning	26
Asphalt Paving Operations	1

It must be pointed out that the emission factors and inventories presented were developed for use in this study of the California South Coast Air Basin and caution must be exercised in their application to other study areas.

4.2.1 Sanitary Landfills

Over 15 million tons of liquid and solid wastes were deposed annually in the 45 major landfill sites within the Basin. Several studies (Refs. 7, 8, 9) indicated that appreciable amounts of methane rich gas were generated due to the biological anerobic decomposition of these wastes. These gases represented not only a potential source of useful energy but a large, currently uncontrolled source of organic compounds to the atmosphere.

No precise estimate of the emissions from landfill operations for the study area existed. Results from the above mentioned references and field tests conducted as part of this program were used to estimate the emissions from these sources.

The approach used was to estimate the rate of carbon escape over the "life" of the fill as presented in a study by the California State Water Quality Control Board (Ref. 10). In this study, it was found that

$$r = \frac{177}{3.75 + 1.95t}$$

where r = rate of carbon escape (lb/ton refuse·yr)

t = age of refuse (years)

Note that it was assumed that carbon is released as both methane and carbon dioxide gas. Using this relation and a gross estimate of the total quality of wastes presently "alive" in the Basin, an estimate of the current organic compound emission rate of 930 tons per day was made.

4.2.2 Petroleum Production Operations

Extensive petroleum production operations were underway in the Basin. Nearly 150 million barrels of crude oil and 115 billion cubic feet of natural gas were produced in 1975. For this inventory only onshore production operations were considered.

Prior to the current study, the magnitude and composition of organic compound emissions from production operations other than tank storage was essentially unknown. Tests were conducted at two locations recommended by the Western Oil and Gas Association as typical of such operations in the Basin. Since only brief test programs were possible during the current program, the emission factors developed should be considered as representative and useful for estimating purposes only.

A summary of the emission factors and inventories used in the current study are given in Table 6. These inventories were made based on data from the California Department of Oil and Gas (Ref. 12), data from local control agencies (Ref. 13) and numerous discussions with representatives of the major petroleum production companies operating in the Basin. It must be reemphasized that the data represented the study area only and conclusions should not be applied arbitrarily to any other situation. Confidence factors on a scale of A to E (A-high, E-poor) were also assigned to assist in the evaluation of these data.

As shown in Table 5, petroleum production operations represented approximately 67 tons per day of which 50% were from storage tanks. The balance were primarily fugitive emissions from leaking valves and metal connections and evaporation from standing oil.

4.2.3 Gasoline Marketing

Organic compound emissions from the transfer of gasoline to automobile tanks has been recognized as a major source of emissions to the atmosphere and has been studied extensively. Control measures were implemented in counties in Southern California to reduce these emissions through vapor recovery techniques at both the tanker truck to storage tank transfer (Phase I) and the nozzle to vehicle tank transfer operations (Phase II). Phase I had been essentially completed within the Basin. Phase II had just been initiated.

Emission factors have been recently revised (Ref. 14) to reflect additional test data on gasoline marketing operations and the effectiveness of these control measures. The emission factors used in this study (given in Table 7) represent not only information from Reference 14 but also

TABLE 6. PETROLEUM PRODUCTION EMISSION FACTORS AND INVENTORIES

Source	Units	Emission Factor	Inventory No. in Basin	Emission Estimate(2) (tons per day)	Confidence Level (3)
Crude Oil Storage Tanks (Fired Roof)	--	(1)	1650 tanks	34	B
Process Drains	lb THC/rod pump well-day	2.0	8000 rod pump wells	8	D
Oil/Water Separators	lb THC/ft^2-day	0.1	184,000 ft^2	9	C
Fugitive Leaks from Valves	lb THC/valve-day	0.10	150,000 valves	8	B
Pump Engine Exhausts	lb THC/10^6 ft^3	1400	4250×10^6 ft^3/yr	1	C
Heaters and Boiler Exhausts	lb THC/10^6 ft^3	30	5100×10^6 ft^3/yr	0	C
TOTAL				60	

(1) Emissions adjusted to 60% of API Bulletin 2518 values based on the Engineering Sciences report, (Ref. 11).

(2) Emissions have been rounded to the nearest ton per day.

(3) Confidence Levels; A - high, E - poor

TABLE 7. GASOLINE MARKETING EMISSION FACTOR

Emission Source	$lb/10^3$ Gal Throughput
Submerged Filling of Underground Tank (Controlled)	0.7
Underground Tank Breathing	1.0
Vehicle Refueling Displacement Loss	9.0
Vehicle Refueling Spillage Loss	0.7

discussions with representatives of the EPA and the San Diego County APCD, one of the most active of the local control agencies in assessing the validity of these emission rates and effectiveness of Phases I and II control measures.

These emission factors have been incorporated with an estimated gasoline sales of 5.3 billion gallons per year (1975) resulting in an average daily emission rate of organic compounds from this source of 83 tons per day for the Basin.

4.2.4 Architectural Surface Coatings

Estimates of the total volume of coatings applied to the surfaces of stationary structure and marketed within the Basin was difficult to make due to the large number of manufacturers and suppliers involved. The most effective approach was to use marketing questionnaires. This approach proved to be a very time-consuming and costly operation without the legal authority to require responses by those questioned.

Surveys that were performed by the local control agencies in California showed that emissions of organic compounds from architectural surface coating applications were from 3.4 to 3.7 tons/1000 people/year. The ARB estimated that 93 tons per day of emissions result from architectural coating within the Basin (Ref. 15) for annual emission factor of 3.3 tons per

1000 people. In the same study it was estimated that total emissions from architectural coating for the entire state amounted to 186 tons per day or an annual emission factor for the state of 3.3 tons per 1000 people consistent with the estimate for the South Coast Air Basin. Thus 3.3 tons/1000 people/year was used in this inventory.

4.2.5 Natural Forest Emissions

Studies (Refs. 16, 17) had shown that there was considerable organic interaction between plant life common to the forest areas in Southern California and the surrounding atmosphere. These emissions are in the form of α-pinenes, β-pinenes and isoprenes generally termed terpenes.

Estimates of the emission rate from typical forest plant life groups had been made by Zimmerman (Ref. 17). A summary of forest group emission rates are presented in Table 8.

Inventories of both the total average and the geographical distribution of forest vegetation were obtained from the National Forest Service (Ref. 18). To these were added estimated acreage of private lands assumed to have similar forest vegetation compositions as in the National Forests. Table 8 also presents a summary of the total acres of each forest group within the study area.

Applying the emission factors and inventory results presented in Table 8 resulted in a total emission rate from these sources of approximately 1150 tons per day. This amount was at least equal to that from all anthropogenic sources within the study area. These results were not surprising since nationally it was estimated that the natural emissions from such vegetations are 3-4 times the man-made emissions (Ref. 17).

TABLE 8. SUMMARY OF NATURAL FOREST EMISSIONS

Forest Type	Total Acreage in Basin (10^3 Acres)	Annual Emission Factor Tons/Acre·Yr	Emissions Tons
Hardwoods	671	0.0211	38.8
Douglas Fir	372	0.0186	19.0
Mixed Conifer	107	0.0782	22.9
Pines	130	0.0963	34.3
Pinjon Juniper	166	0.0353	16.1
Brush	2147	0.172	1011.7
Total	3593		1142.8

SECTION 5.0

FIELD TESTING

Field testing was conducted to determine the rate and chemical composition of organic emissions of representative sources in the Basin. Over 600 samples were collected and analyzed from various equipment in the following locations:

- Adhesives Mfg. Plant
- Aircraft Plant (2)
- Appliance Plant (2)
- Asphalt Plant
- Auto Body Shop (2)
- Automobile Plant (2)
- Chemical Plant (2)
- Dry Cleaning Plant
- Equipment Mfg. (2)
- Gas Compressor Plant
- Gas Pumping Station
- Gasoline Station
- Landfill
- Magnetic Tape Plant
- Oil Field (2)
- Oil Refinery (3)
- Packaging Mfg. Plant
- Printing Plant (2)
- Roofing Kettle
- Rubber Mfg.
- Solvent Mfg. Plant
- Steel Mill
- Utility Boiler
- Utility Gas Turbine

Equipment tested included:

- Adhesive Spray Booth
- API Separator (6)
- Asphalt Paving
- Basic Oxygen Furnace
- Blast Furnace
- Charcoal Adsorbers (4)
- Chemical Mill
- Chemical Process
- Chemical Transfer
- Coke Oven
- Compressors (28)
- Cooling Tower (2)
- Degrease Tank (11)
- Dip Tank
- Dry Clean Tumbler
- Drying Ovens (8)
- Fiberglass Impregnation (2)
- Filling Rack
- Flow Coater (2)
- Gravure Press (5)
- Heater Treater
- I.C. Engines (6)
- Incinerator (10)
- Lithograph (3)
- Open Hearth Furnace
- Paint Booth (32)
- Precip. Outlets
- Printed Circuit Board Proc.
- Process Heater (3)
- Pumps (200)
- Rubber Process (3)
- Sintering Plant
- Sludge Incinerator
- Storage Tank (5) (Species only)
- Sumps (6)
- Valves (24,000)
- Vapor Recovery Tank to Car (8)
- Vapor Recovery Truck to Tank
- Well heads (5)

5.1 FIELD MEASUREMENTS AND SAMPLING

In the field, organic emission rates from stacks and from fugitive emission sources like leaking seals, open ponds or spills were determined. The general approach was either to measure the emission rate or to determine it by calculations from process data or by experiment. From ducted sources, such as stacks, emissions were determined by conventional velocity determinations. Where information was available on the amount of product lost from a process, this was used to determine emissions. Where fugitive emissions due to leaks or spills were involved they were either measured or estimated. In some instances special experiments were conducted to obtain estimates of emission rates. An example of the type of experiments that were conducted involved the determination of the amount of solvent which was emitted from an architectural coating as it was drying or curing. Investigation in this area has revealed that in some instances as much as 30 or 40 percent of the solvent is actually retained in the paint after it is cured, and is not emitted.

For analytical purposes, samples of emission gases were collected in one or more of the following type of containers:

- tubes filled with activated charcoal
- borsilicate glass bottles
- Tedlar bags
- glass bulb containing 1% sodium bisulphite solution (aldehyde determinations).

The charcoal sorbent tubes were used to collect aliphatic organic compounds with carbon numbers of six or greater and all other compounds from C_1 - up. The gas collection jars and bags were used to collect aliphatic compounds with carbon numbers less than six. On most major sources, a combination of sorbent tubes and either bags or bottles were used. Bags or bottles were used for the entire compound range when used for grab sampling.

5.1.1 Sampling Equipment

Two identical portable sampling units were designed and built with the following capabilities:

- measuring stack temperature and velocity
- filtering out particulates larger than 2 microns
- collecting samples in sorbent tubes, glass jars or polybags.

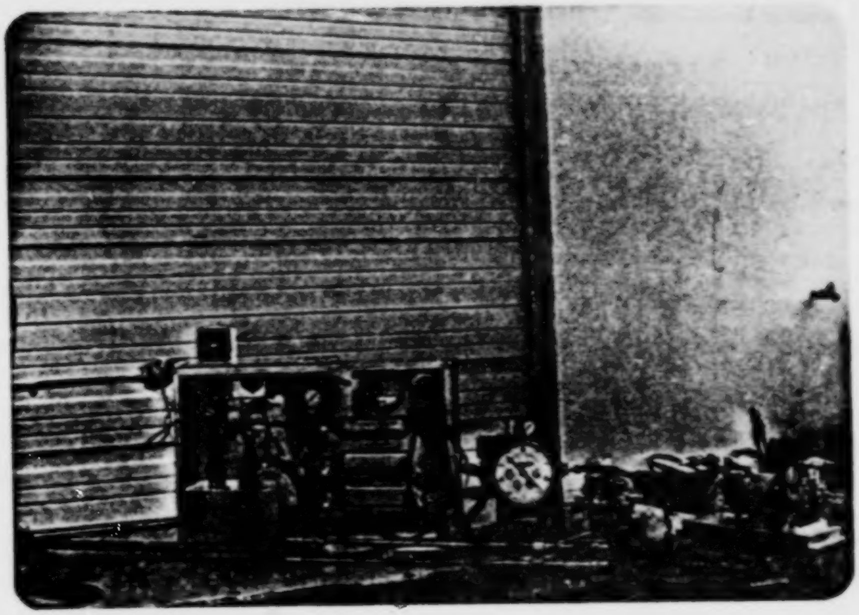
Figure 1 illustrates the assembled sampling trains. Materials of construction are as follows:

- all metal components are stainless steel
- seals are Viton or Teflon
- containers are borosilica glass
- flexible connections are latex rubber of minimal length.

The general flow diagram illustrated in Figure 2 illustrates all components of the assembly which are available to be switched into several sampling modes to conform to requirements dictated by the source to be tested. The components are:

1. a sample nozzle
2. a filter holder with 2.5 micron pore size glass fiber filter
3. a filter and line heater and thermostatic control
4. an impinger train containing LiOH crystals
5. a borosilicate (Pyrex) gas collection bottle
6. a charcoal tube train with thermometer and vacuum gauge
7. a Brooks flowmeter with needle valve flow control
8. various interior and exterior valves and connectors as indicated in Figure 2
9. a meter connection to PD gas meter
10. a Magnehelic velocity gauge and pyrometer for use with a pitot tube.

The lithium hydroxide in the dry impinger train was used only on combustion sources and was selected for use based on experience gained on the Apollo space capsule. Initially an ice water impinger was considered for moisture, NOx, SOx, and CO removal. The problem with this approach was that it was felt that the alcohols and some other oxygenates would form



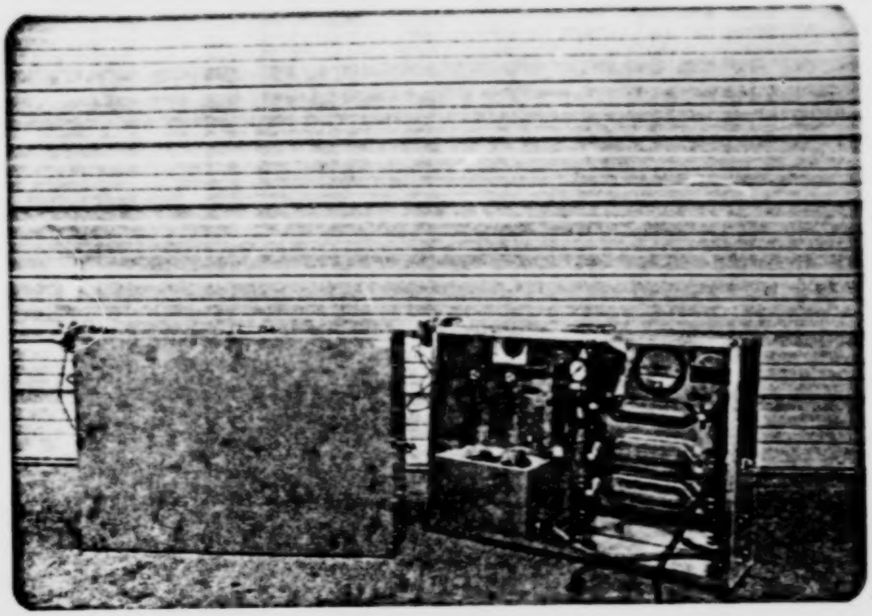


Figure 1. KVB hydrocarbon sampling trains.

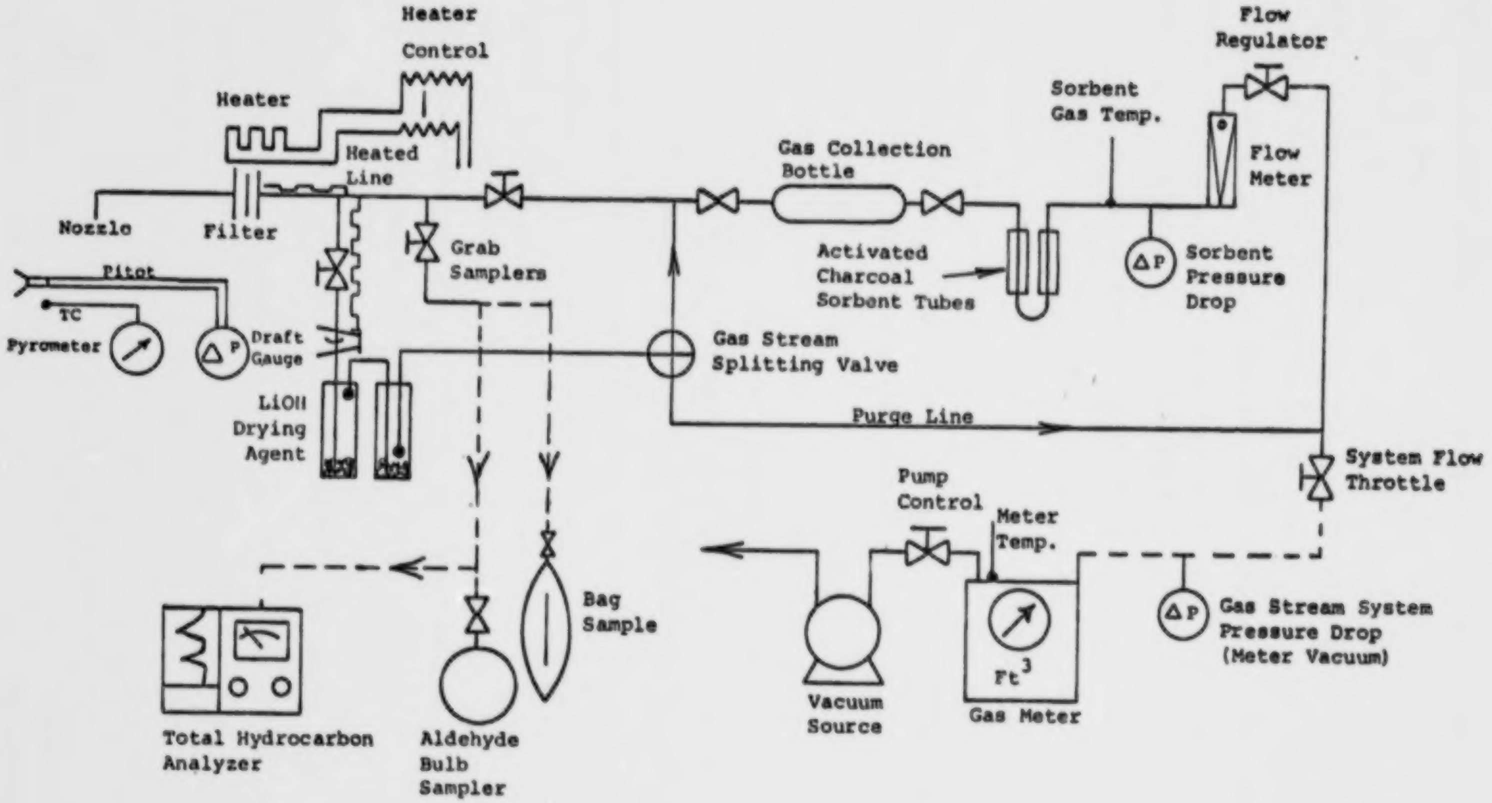

Heater
Control
Heater
Heated
Line
Nozzle
Filter
Pitot
TC
Pyrometer
ΔP
Draft
Gauge
LiOH
Drying
Agent
Grab
Samplers
Gas Collection
Bottle
Activated
Charcoal
Sorbent Tubes
Sorbent
Gas Temp.
Flow
Regulator
Flow
Meter
ΔP
Sorbent
Pressure
Drop
Gas Stream
Splitting Valve
Purge Line
System Flow
Throttle
Pump
Control
Meter
Temp.
Ft³
Gas Meter
Vacuum
Source
ΔP
Gas Stream System
Pressure Drop
(Meter Vacuum)
Total Hydrocarbon
Analyzer
Aldehyde
Bulb
Sampler
Bag
Sample

Figure 2. Complete hydrocarbon sampling train as set up for a hot combustion source (> 180 °F).

P-193

azeotropes with water and would not be easily separated for analysis. (The impinger solution was analyzed for hydrocarbons.) LiOH was used in the Apollo life support system to absorb primarily CO. In the sampling train it also neutralized NOx and SOx which would react with the hydrocarbons. Also the LiOH is hygroscopic and would absorb most of the condensed moisture. Furthermore the LiOH would not adsorb hydrocarbons according to Apollo data. CS_2 extractions and hydrocarbon analyses were made on the impinger contents and they were found to contain no hydrocarbons. On non-combustion sources where moisture was no problem the dry impinger was not employed.

The suitability of several different types of sorbent materials was investigated. The materials tested included: Tenax GC, Carbosieve B, activated charcoal, and XAD-2 resin. The criteria observed in the selection of the sorbent included quantitative retention and recoverability of every analyte possible. These qualities are dimensionalized by measurement of breakthrough volumes and recovery efficiencies. Table 9 presents the breakthrough volumes of the sorbents (25 °C) for hexane and benzene. These analytes were considered to represent about the upper limit of materials that can be analyzed in gas grab samples. Carbosieve B and activated charcoal showed particularly high retention capacities.

Another important parameter in sorbent selection was the analyte recovery efficiency. High temperature thermal stripping (with a purge gas or in a vacuum) of the adsorbed components on Tenax, Carbosieve B and XAD-2 was considered but later rejected because the entire sample must be committed in a single determination. Recovery efficiencies using the thermal/purge-gas techniques also showed high molecular weight discrimination (see Table 10).

TABLE 9. RETENTION EFFICIENCIES OF VARIOUS SORBENTS

	Breakthrough Volumes,* l/g sorbent	
	Benzene	Hexane
Carbosieve B	47	65
Tenax GC	3	4.4
XAD-2 Resin	12	20
Activated Charcoal	30	43

*Measured as the volume of gas/grams of sorbent in cartridge to give a 0.1% FID response to gas stream containing 50 ppm of test component.

P-193

TABLE 10. RECOVERY EFFICIENCY OF PURGE-THERMAL STRIPPING OF SELECTED ANALYTES

	TENAX % Recovery	Carbosieve B % Recovery	XAD-2 % Recovery
Benzene	105	--	--
n-C_7H_{16}	100	11	--
n-C_8H_{18}	99	<1	--
n-C_9H_{20}	94	<1	--
n-$C_{10}H_{22}$	72	<1	62
n-$C_{11}H_{24}$	67	<1	60
n-$C_{12}H_{26}$	67	<1	--
n-$C_{13}H_{28}$	58	<1	--
n-$C_{14}H_{30}$	56	<1	--
n-$C_{15}H_{32}$	61	<1	--
n-$C_{17}H_{34}$	46	<1	--

Solvent stripping for analyte elution prior to chromatographic analysis was investigated. Carbon disulfide was found to be an attractive solvent because of its excellent solvent properties. Many of the other common solvents, such as methylene chloride, chloroform, hexane, benzene, etc., tend to swamp the chromatogram, obliterating any signals of components that have boiling points even decades higher.

Unfortunately, it was found that Tenax GC is soluble in CS_2 as well as in CH_2Cl_2. Carbosieve B showed poor recoveries with solvents. Testing was therefore primarily focused on solvent extraction of activated charcoal with CS_2 and XAD-2 resin extraction with CH_2Cl_2 (CS_2 also dissolved XAD-2). Table 3-4 presents the results. Mueller and co-workers (Ref. 19) have reported similar efficiencies for halogenated and oxygenated hydrocarbons using charcoal adsorption followed by CS_2 elution. Based on the data they presented and the precedent set by the National Institute for Occupational Safety and Health (NIOSH) in the selection and published (Refs. 20 to 22) characterization of the charcoal/CS_2 analysis scheme, the use of coconut-derived activated charcoal as supplied by Mine Safety Appliances or SKC, Inc. was selected as the material of choice for source sampling.

The total hydrocarbon analyzer shown in Figure 2 is the Bacharach TLV Sniffer which was used to provide an indication of hydrocarbon concentration levels and process variations. At under $1000 in price it served its purpose well.

5.1.2 Sampling Method

The sampling train shown in Figure 2 was used or modified for each sampling. It was already mentioned that the LiOH impingers were removed for other than combustion tests. On some simple one solvent sources even the charcoal was omitted and only a gas bottle sample was obtained.

On fugitive sources the approach taken is shown in Figures 3 through 6. Figure 3 shows the setup for measuring leak rates when the rate is so great that it will drive the meter itself. Most large pipeline leaks are of this type. Figure 4 shows the setup if the leak will not drive the meter. A pump is added to draw filtered air through the bag. The measured flow rate times the hydrocarbon concentration measured by sampling the gas provided a measure of the hydrocarbon emission rate.

Figures 5 and 6 illustrate test setup for sampling a high temperature fugitive emission source. In Figure 5 aluminum foil was substituted for polyfilm and rates were measured as Figure 3 or 4. When the source was too hot, the foil could not be attached and the setup in Figure 6 was used. The temperature of the source was measured, a grab sample was obtained in a gas collection bottle, and the concentration of total hydrocarbons was measured. The leak rate was then obtained by applying engineering judgments.

5.2 LABORATORY ANALYSIS

Most ambient pressure gas samples were analyzed within 2-3 days following receipt, except for a small number that were processed as long as two weeks later. Several tests were made with synthetic samples to evaluate storage effects on the contents of capped charcoal sampling tubes. Recoveries did not change, within experimental error, between 24 hours and

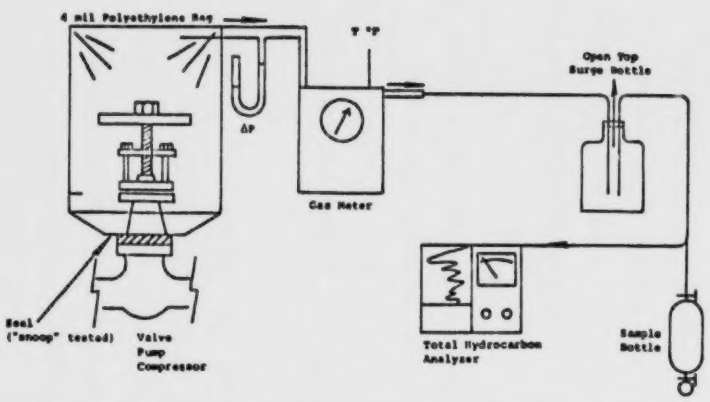

4 mil Polyethylene Bag
T °F
ΔP
Gas Meter
Open Top
Surge Bottle
Seal
("snoop" tested)
Valve
Pump
Compressor
Total Hydrocarbon
Analyzer
Sample
Bottle

Figure 3. Leak rate and concentration measurement of ambient temperature fittings. High leak rates.

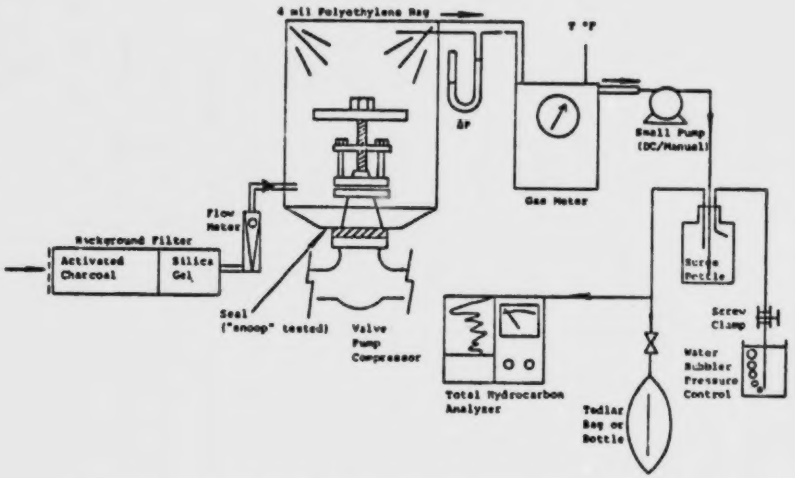

4 mil Polyethylene Bag
T °F
ΔP
Gas Meter
Small Pump
(DC/Manual)
Flow
Meter
Background Filter
Activated
Charcoal
Silica
Gel
Surge
Bottle
Screw
Clamp
Seal
("snoop" tested)
Valve
Pump
Compressor
Total Hydrocarbon
Analyzer
Tedlar
Bag or
Bottle
Water
Bubbler
Pressure
Control

Figure 4. Leak rate by dilution sweep and sampling of ambient hydrocarbon fitting. Low leak rates.

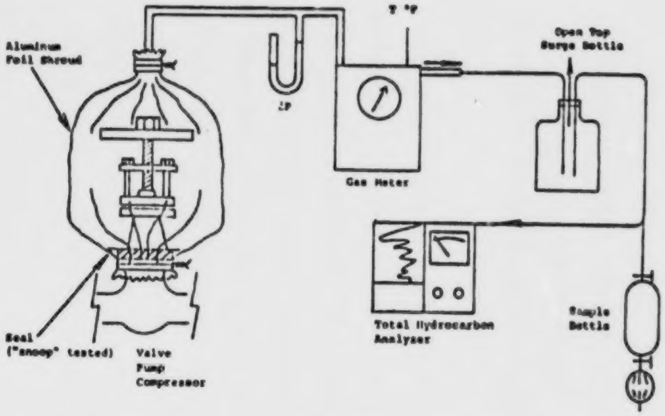

Aluminum
Foil Shroud
ΔP
T °F
Gas Meter
Open Top
Surge Bottle
Seal
("snoop" tested)
Valve
Pump
Compressor
Total Hydrocarbon
Analyzer
Sample
Bottle

Figure 5. Leak rate measurement and concentration measurement of high temperature fitting.

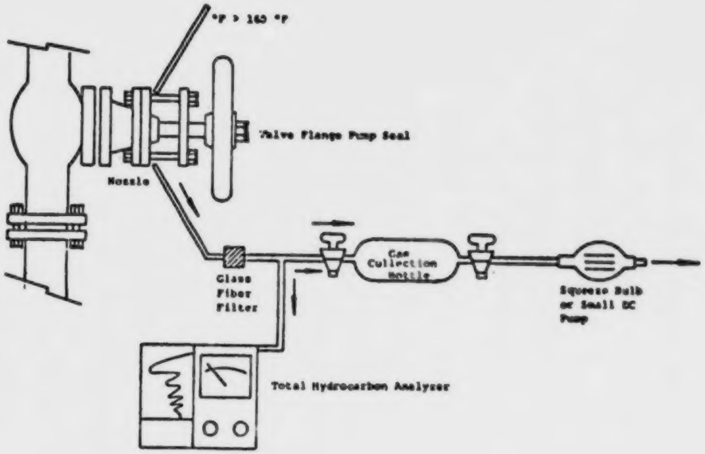

°F > 160 °F
Valve Flange Pump Seal
Nozzle
Glass
Fiber
Filter
Gas
Collection
Bottle
Squeeze Bulb
or Small DC
Pump
Total Hydrocarbon Analyzer

Figure 6. Hydrocarbon sampling from hot oil or solvent transfer.

30 days. Therefore, the charcoal samples could stand for longer periods without fear of losses, and were not usually analyzed until after the gas samples in the same sets had been analyzed. The charcoal eluates were usually run within an hour after the carbon disulfide was added to displace the sample components.

Initial analysis of all samples was conducted using a gas chromatograph (GC). Lower boiling component identifications were based on retention times established by repeated analyses of standards. If there were questions as to the positive identity of a GC peak, the sample was rerun using GC/MS methods for the identification. This approach was often necessary because a number of chromatographic peaks contained at least two and sometimes three components. The mass spectra also provided a basis for determining ratios of the components in the GC peak being examined. These data were then used in making quantitative measurements of the contents of chromatographically unresolved but computer-integratable peaks.

A Beckman Model GC-55 equipped with a precision temperature programmed column oven and a flame ionization detector (FID) was used for most of the GC work performed on the program. The column used was 1/8" O.D. by 6 ft. long stainless steel tubing containing a stationary phase of 100-200 mesh Poropak Q. Using the analtyical conditions described below, this column furnished good resolution of the lowest boiling materials encountered while still eluting with good results the higher boiling hydrocarbons representing the top of the range of interest.

Analyses were performed using helium as the carrier gas at a flow rate of 30 cc/min. Detector gas flows were: H_2 - 40 cc/min; air - 300 cc/min. The following conditions were used for GC analyses: 6 min. at 40 °C followed by temperature programming at 10 °C/min to 190 °C and isothermally held at 190 °C for approximately one hour.

The GC column effluent of the Beckman GC-55 gas chromatograph was split into two streams. One stream was directed to the FID of the GC, the other to a heated transfer line which carried the stream to a Finigan Jet Separator and into the mass spectrometer. The separator provided a twenty fold concentration of the material of interest in the gas stream.

The mass spectrometer used on this program was a Consolidated Electrodynamics Corporation (CEC) Model 21-104. This was a 180 degree magnetic sector instrument having an electron impact ion source and an electron multiplier detector system which permitted moderately high-speed mass scanning.

Multiple MS scans were taken when a GC signal was observed on the strip chart recorder. Multiple scan studies indicated that approximately 2 seconds were required for the maxima to be observed by the MS. Multiple scans were required to insure representative ion pair formation.

Mass spectra were interpreted manually using such reference works as:

- "Compilation of Mass Spectral Data," Cornu, A. and R. Massot, Heyden & Son, Ltd., London, England, 1966.
- "Index of Mass Spectral Data," AMD II, American Soc. for Testing and Materials, Philadelphia, 1969.
- "Eight Peak Index of Mass Spectra," Atomic Weapons Research Establishment, Aldermaston, England, 1970.
- "Atlas of Mass Spectra Data," Stenhagen, E., et al., Interscience, New York, NY, 1969.
- "API Project 44 Selected Mass Spectra Data," Thermodynamics Research Center, Texas A&M University.

When an unknown peak could not be positively identified by this means, the spectrum was compared with the mass spectra of some 27,000 different compounds in the library of the Cyphernetics Corp. Mass Spectral Search System. This computerized search system is directly accessible on a time-shared basis. It was successfully used to verify assignments made during the earlier work on this program.

A spectrophotometric method similar to that specified by the NIOSH was used for the determination of aldehydes. The total volume of liquid in the aldehyde sample bulbs was measured, and an aliquot taken for the determination. The sample was allowed to react with a modified Schiff's reagent prepared from rosanaline hydrochloride and sodium bisulfite. After a suitable development time, the adsorbance was read at 580 mμ against a reagent blank on a UV-vis spectrophotometer. Concentration was read from a calibration curve. The same determination was performed on a sample of the sodium bisulfite used for collecting/stabilizing the aldehydes and a 1 µg/ml formaldehyde standard. Results were calculated and reported as total micrograms of formaldehyde equivalent in the sample. The minimum amounts of aldehydes that can be detected by this method are typically 1-3 µg total (as formaldehyde).

5.3 QUALITY CONTROL

Despite a program budget which limited the special tests designed for quality assessment every effort was taken in the field and laboratory to obtain as accurate and precise data as possible. A consulting firm, EcoScience Systems, Inc. of Riverside, California* was retained to supervise the quality program, i.e. specify tests to be conducted and procedures to be followed and determine the overall error in data. Calibration gas mixtures, round robin testing, unknown blank samples, redundant samples were techniques used to determine the measurement error which was assessed to be as follows:

- the calculated total hydrocarbon emissions were good to within ± 25%
- values for the emissions of individual hydrocarbons, however, were less certain than that for total hydrocarbons
- the sum of the errors in sampling and analyses for individual alkanes probably was in the range of 25-50%, and
- the concentrations of oxygenates, aromatics and halogenates must be considered lower limits only with the possible error being a factor of three or more.

---

*Principals included: Dr. James N. Pitts, Jr., Dr. Daniel Grosjean and Dr. Barbara Finlayson-Pitts

REFERENCES

1. Environmental Protection Agency, "Comprehensive Data Handling Systems, Emissions Inventory/Permits and Registration Subsystem (EIS/P&R) Program Documentation and Users Guide," February 1975.

2. Grisinger, J. E., "Development of Coordinate System Transformation Equations Required for Air Quality Modelling in the SCAB," CARB Staff Report, July 1977.

3. Environmental Protection Agency, "Compilation of Air Pollution Emission Factors," Supplements 1-7, Publication AP-42, April 1977.

4. Trijonis, J. C. and Arledge, K. W., "Impact of Reactivity Criteria on Organic Emission Control Strategies in the Metrolopitan Los Angeles AQCR," Report for EPA Contract 68-02-1735, July 1975.

5. Environmental Protection Agency, "Compilation of Air Pollution Emission Factors," Supplements 1-7, Publication AP-42, April 1977.

6. Personal communication with Wayne Zwiacher, SCAQMD.

7. Mery, R. C. and R. Stone, "Sanitary Landfill Behavior in an Aerobic Environment," Public Works, January 1966.

8. MacFarlane, I. C., "Gas Explosion Hazards in Sanitary Landfills," Public Works, May 1970.

9. Dair, F. R. and R. E. Schwegler, "Energy Recovery From Landfills," Waste Age, March/April 1974.

10. California State Water Quality Control Board, "In-Situ Investigation of Movements of Gases Produced From Decomposing Refuse," Publication No. 31, 1965.

11. Engineering Science, Inc., "Hydrocarbon Emissions from Fixed-Roof Petroleum Tanks," Western Oil & Gas Association, July 1977.

12. California Division of Oil and Gas, "Sixty-first Annual Report of the State Oil and Gas Supervisor," Report Number PR06, 1975.

13. Personal communications with Robert Murray (SCAQMD) and Greg Barbario, (VCAPCD) and John Laird (SBAPCD).

14. Burklin, C. E. and Honnekamp, R. L., "Revision of Hydrocarbon Evaporative Emission Factors," EPA 450/3-76-039, August 1976.

15. Air Resources Board, "Consideration of Model Organic Solvent Rule Applicable to Architectural Coatings," Staff Report, June 1977.

16. Rasmussen, R. A., "What Do Hydrocarbons from Trees Contribute to Air Pollution," Journal of the APCA, Vol. 22, No. 7, July 1972.

17. Personal Communications with Pat Zimmerman, Washington State University.

18. Personal Communications with Mike Welsh, San Bernardino National Forest, National Forest Service.

19. Mueller, F. X. and Miller, J. A., "Determination of Organic Vapors in Industrial Atmospheres," Amer. Lab., 49-61, May 1974.

20. Levache, B. and MacAskill, S. M., "Analysis of Organic Solvents Taken on Charcoal Samplers," Anal. Chem., 48, (1), 76-78, 1976.

21. Nelson, G. O., et al., "Respiratory Cartridge Efficiency Statistics; VII. Effect of Relative Humidity and Temperature," Amer. Ind. Hyg. Assoc. J., 37, (5), 280-288, 1976.

22. Parkes, D. G., et al., "A Simple Gas Chromatographic Method for the Analysis of Trace Organics in Ambient Air," Amer. Ind. Hyg. Assoc. J. 37, (3), 165-173, 1976.

CONDENSED DISCUSSION

QUESTION: What provisions do you have for updating the inventory?

ANSWER: KVB does not have any contract or any responsibility for updating it, per se. We have turned over a data system in EIS format on tape. If one wanted to update and change emission factors, the program is written in this way. If someone wants floating roof tanks, for example, reduced by 60%, we can do that. The program is set up that it can be done. We will give to ARB a complete set of documentations so they will know how to do it. Not being a programmer myself, I don't really know how easy that is done. Also emission profiles can be changed by source classification code.

"HIGHWAY MOTOR VEHICLE EMISSION FACTORS"

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By
Motor Vehicle Manufacturers Association
of the United States, Inc.
For Presentation at EPA Emission
Inventory/Factor Workshop
300 New Center Building
Detroit, Michigan 48202
September 13-15, 1977

Presented by
Walter S. Fagley, Jr.
Chrysler Corporation
P. O. Box 1118
Detroit, MI 48288

Abstract

The MVMA commends the holding of this workshop intended to bring together information on the current status, uses and needed improvements relating to emission factors and inventories. The emission factors and inventory data are a necessary part of information to relate the complex phenomena of emissions and air quality.

The purpose of this paper is to provide MVMA's comments on the June, 1977, EPA Interim Document entitled "Mobile Source Emission Factors" eventually to be published as a supplement to AP-42.

The EPA document represents a monumental effort and consequently these comments are not intended to be exhaustive. While the Interim Document provides substantially improved discussions of the methodologies used to derive the emission factors, it lacks complete and detailed documentation of the experimental data base and the computational and judgmental methods used for translating those data into emission factors.

The major thrust of this paper is on passenger car exhaust and evaporative emission factors. The paper reviews data from past emission surveillance programs and compares the results to the emission

factors contained in the Interim Document. It is concluded that emission levels from uncontrolled cars varied with model years. However, a single set of "benchmarks" from which to judge progress is needed and the 1960 model year was selected for this purpose. Analysis shows that the 1960 model year baselines are 19 g/mi HC (10.6 exhaust, 4.3 evap., and 4.1 crankcase), 84 g/mi CO and 4.1 g/mi NOx. Exhaust emission values are based on the 1975 Federal Test Procedure.

In estimating the contributions of vehicle emissions to overall air quality, the emission factors for controlled cars--past, present, and future--are more significant than emissions from uncontrolled cars. The EPA Interim Document appears to substantially overstate emissions from controlled cars. The overstatement of expected emission rates for future cars is very large, if one concedes even moderate success by both manufacturers and regulators to improve emission performance of in-use vehicles.

Introduction

The purpose of this paper is to comment on the motor vehicle emission factors contained in the June, 1977 EPA Interim Document entitled "Mobile Source Emission Factors" (Reference 1). This EPA Interim Document has been proposed to eventually revise the previous mobile source emission factors that are contained in the October, 1975 Supplement No. 5 to AP-42. In commenting on the proposed revision to Supplement 5, it should be pointed out that the basic purpose of AP-42 is to provide a compilation of emission rate data without attempting to relate the complex phenomena of emissions and ambient air quality. Because air quality models are continually being revised and improved, it is entirely proper to place the responsibility of correctly applying the emission factors with the user of AP-42.

However, we believe the users of AP-42 should be aware of the uncertainties involved in the emission factors. Data can only be intelligently applied if the user is fully aware of the associated questions and qualifications. It is to the credit of EPA that this workshop allows airing of any controversy related to its published emission factors. In this same spirit, we appeal throughout this paper for more complete documentation of the bases for emission factors to be published in the future. Such documentation would afford all future users some of the advantages which will accrue to the attendees of this workshop.

This paper deals with mobile source emission factors and discusses some of the problems and uncertainties in the application of emission factors. Most of the discussion centers on data related to the 1975 FTP certification driving cycle and procedures developed to simulate urban driving, low average speed, under conditions which may contribute to peak oxidant pollution. There are, however, other urban driving cycles and procedures characterized by low average speed (under 20 mph), such as the US 7-mode, the European ECE Regulation 15 and the Japanese hot 10-mode and cold 11-mode cycles.

Although the low speed urban FTP cycle is the basis for U.S. certification, some effort has gone into characterizing emissions under other conditions. Emission data are sometimes available on special purpose cycles such as the EPA highway and sulfate cycles; the SAE urban, suburban, and interstate driving cycles; and on various short test cycles that are under investigation to find a less expensive way of measuring emissions. Since emission rates can be quite different on each of these cycles, care should be exercised in deciding which cycle and what adjustments are necessary for the particular application at hand. In practice, one usually selects the cycle for which there are data and then may make appropriate adjustments if needed. Suggested procedures for adjustments are included in AP-42 related to the 1975 FTP certification cycle which is usually the cycle selected for current applications in the United States. The validity of such adjustments is still under investigation.

As one example, EPA is currently studying the possibility that the emission factors generated using the 1975 FTP driving cycle overestimate the relevant CO emissions. This would be due to the fact that the 1975 FTP cycle has a cold start causing FTP CO emission factors to be relatively high compared to hot vehicle operation, particularly for catalyst cars. Since most vehicles are usually warmed up by the time they reach (and have influence on) a CO "hot-spot" in a city, the 1975 FTP cycle would not be appropriate and should be adjusted for such cases. Since traffic flow varies during the day and during the year, speed correction factors and other adjustments should be based on the conditions leading to high ambient CO concentrations rather than blindly using only the FTP cycle emission factors.

When applying emission factors, one has to deal with the definition of "ambient air" which is not precisely defined. At the tailpipe, CO emissions are concentrated. Somewhere between the tailpipe and people the air quality standard is intended to be achieved. Exactly where this point occurs depends primarily on judgment. For example, New York City is reported to have the worst carbon monoxide pollution problem in the United States, based on EPA and New York City measurements. However, part of the reason for the relatively high CO measurements is due to differences in the location of the measurement equipment. In New York City the sampling probe is closer to automotive tailpipes than sampling probes in other cities allowing less time for dilution of carbon monoxide. According to the President's Council on Environmental Quality (Reference 2):

> "The New York City location of the sampling probe was at 8 feet above the curb; all other sites measured CO at heights of 8 to 18 feet, but at the building face several feet back from the curb. One would expect that if the New York measurements were made at the building face, as in other cities, the measured CO levels and their frequencies of occurrence would be somewhat lower. Mobile monitoring data taken by the local New York agency support this conclusion."

It would be extremely unfortunate if transportation control plans were established from measurements based on the shortest distance between sampling probe and tailpipe without considering public health impacts.

It has been assumed in the past that the exhaust emissions from cars built prior to first exhaust control in 1968 (1966 in California) could be represented by a single set of emission rates irrespective of model year. Such values have been important not only as emission factors used in calculation of emission inventories, but as "benchmarks" from which progress in emission control could be based. Analyses developed later in this paper lead us to conclude that this assumption is incorrect.

As time progresses, the fraction of total vehicle miles traveled (VMT) represented by pre-controlled cars becomes smaller and smaller. Furthermore, the proliferation of air monitoring equipment has substantially decreased the possibility of interest in selecting "base years" for air quality projection calculations which would involve a dominant fraction of total VMT accounted for, by uncontrolled cars. Therefore it might be argued that concern over the emission levels from such cars is academic. While this may be largely true for the emission factors use of uncontrolled car emission levels, there remains a need for a set of benchmarks from which to judge progress. It has little meaning to the layman to state that today's cars are controlled to carbon monoxide emission levels of 15 g/mi. However, one can make a reasonable judgment from the statement that passenger car CO emissions are controlled to 82% of the level from uncontrolled cars. We therefore believe it is desirable to have the best possible assessment of emission levels from uncontrolled cars from available information.

However, since the best information argues against a single set of uncontrolled car emission rates, it is necessary to select a model year definition of the desired benchmark. We have chosen to define this benchmark as a 1960 model year passenger car. The reason for this choice is that 1960 was the most recent model year for which there were no emission controls. The positive crankcase ventilation system (PCV) to control blow-by crankcase emissions was introduced in 1961 in California. Nationwide installation began in 1963. To complete the history, exhaust emission control was first established in California for 1966 model year vehicles. Federal exhaust emission control was first applied for model year 1968 vehicles. In 1970, evaporative emission control was added to California vehicles and nationwide in 1971. Therefore, an uncontrolled evaporative vehicle could be defined as a 1969 or older vehicle.

Due to the different dates for implementing emission controls, a number of possible definitions of uncontrolled vehicles could be made. Although model year 1960 was selected to represent baseline emissions for completely uncontrolled passenger cars, data from other model years are also presented for comparison should a different definition be desired.

Uncontrolled Crankcase Emissions

Uncontrolled crankcase emissions were listed as 4.1 g/mi hydrocarbon in EPA's Interim Document. It appears that the 4.1 g/mi crankcase emission rate for 1959-1962 cars was obtained from the work of Kramer and Cernansky (Reference 3). This value was estimated by assuming an average blow-by volume of 1.1 cfm and an average hydrocarbon concentration of 15,000 ppm (as hexane) and an average urban area speed of 25 miles per hour. Blow-by flow depends not only upon vehicle speed but also upon fuel tetraethyl lead concentration and mileage (Reference 4). We are aware of no data which would indicate the 4.1 g/mi rate is not a good estimate; therefore, we endorse that value.

Uncontrolled Exhaust Emissions

Sources of data on in-use exhaust emissions from 1965 and older vehicles are listed in Table 1. Since the Federal Test Procedure for exhaust emissions has changed several times over the past, some of the earlier data must be converted in order to compare to more recent data using the 1975 FTP (see the Appendix for a discussion of conversion factors). There are uncertainties in this conversion process. However, since the largest body of data on uncontrolled passenger cars (over 1,200 vehicles) was taken using tailpipe concentration measurements, this estimation of 1975 FTP emissions was considered worthwhile. The conversion was found to compare favorably with measurements on uncontrolled vehicles using the 1975 FTP procedures directly.

Data on uncontrolled exhaust levels are contained in Table 2 and are plotted in Figures 1, 2 and 3. The "mean line" in each Figure was plotted based on a 2nd degree regression analysis according to the methodology outlined in the Appendix. It is interesting to note that uncontrolled exhaust emissions appear to have changed over time. Hydrocarbon and carbon monoxide emissions appear to have decreased from 1947 to 1965 while NOx increased. One reason for this change can be attributed to a shift in model mix incorporating greater numbers of automatic transmissions. Other changes in engine design (e.g., increasing compression ratios and the shift from L-head to overhead valve engines) also had their effect.

Based on the "mean line" in Figures 1, 2 and 3 the uncontrolled (model year 1960) baseline exhaust emission level on the 1975 FTP is 10.6 g/mi HC, 84 g/mi CO, and 4.1 g/mi NOx. Emission levels in EPA's Interim Document for model year 1960 cars driven in calendar year 1970 were listed as 9.9 g/mi HC, 124.8 g/mi CO, and 3.4 g/mi NOx. The basis for EPA's numbers is not clear. Carbon monoxide emissions appear excessively high. There appears to be an obvious need for better documentation of the basis for that value.

Uncontrolled Evaporative Emissions

Table 2-13 in EPA's Interim Document includes evaporative emission rates in grams per mile for light duty gasoline powered vehicles. A value of 2.53 g/mi was used for cars without evaporative emission controls through and including model year 1970.

There is a preponderance of evidence demonstrating that this emission rate for cars without controls is incorrect. This rate errs on the low side as a result of neglecting fuel tank running losses.

In addition, there is a less serious but still important controversy over conversion of the regulatory gram per test basis for expressing evaporative emissions to the more useful g/mi basis. The first apparent publication of such a conversion was made by Professor John B. Heywood of MIT (Reference 5). Professor Heywood proposed the following formula:

$$\text{EVAP g/mi} = \frac{\text{DS g/day}}{\text{27 mi/day}} + \frac{\text{HS g/test}}{\text{7.5 mi/test}}$$

Where DS = Diurnal Soak Emissions

Where HS = Hot Soak Emissions

The EPA Interim Document, on the other hand, used the following formula:

$$\text{EVAP g/mi} = \frac{\text{DS g/day} + \text{3.3 trips/day} \times \text{HS g/test}}{\text{29.4 mi/day}}$$

The 3.3 trips per day and 29.4 miles per day values are indicated to be national averages.

To illustrate the magnitude of the difference between these computational methods, the EPA Interim Document uncontrolled value of 2.53 g/mi would become 2.92 g/mi under the MIT method. While there is a difference of approximately 2-1/2 miles per day between these two methods, the more important discrepancy is the effective miles per trip difference. The Interim Document 29.4 mi/day with 3.3 trips per day amounts to 8.9 mi/trip compared to the 7.5 mi/trip of the MIT method. While numerically smaller than the mi/day discrepancy, this is fractionally a larger difference. In the case of controlled cars, the daily mileage divisor generally operates on a substantially smaller g/test value, thus it makes little difference in the diurnal soak contribution to the g/mi value, whether one assumes a daily total of 27 or 29.4 miles.

Since urban emissions are of concern, it would appear that urban statistics rather than national average statistics should be the basis of emission computations. Urban statistics are presumably the basis of the exhaust emission 7.5 mile "test trip" and since this is the actual trip which "drives" the measured hot soak emissions, it seems more reasonable to us to select the 7.5 mile per trip value.

The Interim Document emission factor of 2.53 g/mi is based on data from EPA's Emission Factors Surveillance Programs, primarily the FY 71 program (Reference 9). The FY 71 program unexplainably neglected to include measurement of tank running losses on uncontrolled cars. Virtually all gasoline powered passenger cars built in the last 40 years used vented fuel tanks (prior to evap. control). Since automobile fuel tanks are heated during operating of vehicle as a result of engine heat rejection, the tank vapor space will necessarily exhale HC vapors (and air) through the tank vent during driving periods. However, for the purpose of emission factors, 10 g/test is a representative value (Reference 8). Therefore, we recommend the following formula be used:

$$\text{EVAP g/mi} = \frac{\text{DS g/day}}{\text{27 mi/day}} + \frac{\text{HS + RL g/test}}{\text{7.5 mi/test}}$$

Published values of running losses from automobile fuel tanks (References 6 and 7) vary from 8 to 52 g. If this latter value is added to the 14.7 g/test hot soak value of EPA's Interim Document for the uncontrolled car and the MIT method of conversion is applied, a "correct" value for the uncontrolled car of 4.3 g/mi is obtained.

It is recommended that first the regulatory test-to-g/mi emission rate conversion be based on the MIT method; secondly, that the emission factor for cars without evaporative emission controls be corrected to include tank running losses, specifically a value of 10 grams for the LA 4 test. This would result in an uncontrolled emission rate of 50.6 grams per test or 4.3 g/mi.

Uncontrolled Baseline Summary

Based on the above analysis, the following baseline was determined (1960 model year):

	HC	CO	NOx
Exhaust	10.6 g/mi	84 g/mi	4.1 g/mi
Evap	4.3	---	---
Crankcase	4.1	---	---
TOTAL	19.0 g/mi	84 g/mi	4.1 g/mi

Emissions from Controlled Vehicles

Controlled Crankcase Emissions

It is indicated in the Interim Document that "...crankcase hydrocarbon emissions from post-63 vehicles are negligible." The values in Table 2-13 of that document, on the other hand, imply a crankcase emission rate for MY 1963-1967 of 0.8 g/mi. This is consistent with the information in Reference 3 that the so-called open crankcase ventilation system applied during those model years was 80% effective in controlling crankcase hydrocarbon emissions.

We believe the implied 0.8 g/mi rate for MY 1963-67 is a reasonable estimate and suggest the text be altered to correct the associated error. A separation of the tabular values for crankcase and evaporative emission factors in the Interim Document would further clarify the situation.

We concur with the post-1967 crankcase emission factor of zero, as given in the Interim Document. The "closed positive crankcase ventilation system" used since that time vents both the crankcase air inlet and the ventilation outlet to the engine induction system. Since crankcase blow-by emissions can only occur with the engine operating, and the engine induction system is under negative pressure when the engine is operating, it is not possible for emissions to escape from the crankcase directly to the atmosphere.

Controlled Exhaust Emissions

Sources of data on in-use exhaust emissions from controlled passenger cars are listed in Table 3. Most of these data come from EPA's in-use surveillance programs. Analysis of these data will be divided into 1968 to 1974, and post-1974 model year categories.

- Post 1974 Cars

Tables 2-1 and 2-2 in EPA's Interim Document list a common set of HC and CO exhaust emission factors (over the life of the car) for model years 1975 through 1978. The tabulation on page II-9, on the other hand, lists equations for computing emission factors as a function of chronological age for several standards scenarios which might apply to post-1978 cars. These emission factors reflect extremely high additive "deterioration rates", particularly with respect to the applicable emission standards. The accompanying text (pages II-6 and II-7) indicates that these emission factors were obtained from mileage regressions of FY 1974 program data of 1975 cars -- with some adjustments made (in the case of CO) to compensate for "... bias due to the rapid deterioration of the maladjusted vehicles..."

On Figures 4 and 5 the HC and CO emission factors are plotted from EPA's Tables 2-1 and 2-2 as a function of miles based on the Interim Document's indicated assumption of a constant 10,000 miles per year. The figures also contain linear regressions of the individual 1975 car data from the FY 1974 program (Reference 10). In the case of exhaust HC, there is virtually a perfect match of the least squares straight line fit of the data with the Interim Document emission factors of Table 2-1. In the case of the CO data (Figure 5) the change stated in the Interim Document made to the slope of the linear fit for the "maladjustment bias" is evident.

The actual mileage extent of the test data in Figures 4 and 5 was only slightly over 40,000 miles. Thus, the extension of those lines to the entire life of the car represents substantial extrapolation -- and possible large errors. Furthermore, the data are assumed to be represented by a straight line. The correlation coefficients of .195 and .127 for the HC and CO data respectively suggest that this is an arbitrary assumption.

Also shown in Figures 4 and 5 are the plot of a least squares fit of a logarithmic mathematical model, perhaps as equally arbitrary as a linear model but, on the other hand, just as rational (correlation coefficients with the log model are also low at .164 and .133 for HC and CO respectively). The logarithmic model of these alternate curves is similar to that employed by the California Air Resources Board for a number of years in analyzing its surveillance data (Reference 11 for example). The logarithmic model suggests substantially lower emission factors, particularly at the higher mileage associated with vehicle ages beyond four or five years. The logarithmic model assumes that the rate of deterioration of exhaust emissions will be a continually decreasing function of miles. It is suggested that this is consistent with the assumption made in the Interim Document that emission levels cease to deteriorate after 10 years or 100,000 miles. At some point emissions would cease to increase with age.

Data on NOx are plotted in Figure 6. The linear regression line through the FY 74 data has a significantly lower slope than that of the Interim Document emission factors. Further, the logarithmic fit of the FY 74 data shows very low deterioration beyond the initial 20,000 miles. It is believed the latter is more consistent with actual observations of high mileage NOx emissions. It is a common observation that if CO emissions increase with mileage as a result of air/fuel ratio richening, NOx emissions are expected to decrease concurrently.

The brief analysis represented by Figures 4 to 6 strongly suggests that the very large deteriorations assumed by the emission factors -- even for 1975 cars -- are unrealistic. Furthermore, the assumption that such levels of deterioration will continue indefinitely for future model years is even more unrealistic. While any assessment of the FY 74 data indicates that CO emission levels from 1975 cars are unfavorable relative to the applicable standard, it is reasonable to expect that situation to improve as a result of the normal "learning curve" process.

Moreover, there is activity underway both by the manufacturers and within the regulatory community to reduce the probability and magnitude of field maladjustment which appears to be contributing so substantially to this discrepancy between in-use car emissions and their certification levels (References 12, 13, 14).

Given the present statutory and regulatory climate for air pollution control, the consequences of grossly overstating probable emissions from future passenger cars is profound. MVMA, therefore, strongly urges that the analytical bases and assumptions used to generate the post-1974 model year exhaust emission factors of the Interim Document be re-examined.

- 1968 through 1974 Cars

It is disconcerting that the emission factors for these model years listed in Tables 2-1 and 2-2 of the Interim Document show the same levels of exhaust hydrocarbon and carbon monoxide control throughout. The HC and CO standards, on the other hand, represent three levels of control with stringency of the original 1968 standards (1966 in California) having been increased in 1970 and again in 1972. The oxides of nitrogen emission factors of Table 2-3 appear to be at least directionally consistent with the certification standards throughout these model years.

These emission factors are indicated by the Interim Document to be based on the data from EPA's Emission Factors Surveillance Programs of Fiscal Years 1971, 72, 73 and 74. The data for those programs prior to the FY 74 program have not been available to us in the form which facilitated the analysis of Figures 4 through 6 for the 1975 cars -- data for which were included only in the FY 74 program. However, test data for some vehicles of the 1968 through 1974 model years were included in the FY 74 program. We have consequently performed similar analyses of those data comparing the logarithmic with the linear model.

Figures 7 through 9 depict those analyses for the 1974 model data illustrating that the relationship of the logarithmic to the linear models are generally similar to that shown in Figures 4 through 6 for the 1975 model year -- again suggesting that the linear model overstates the emission rates at relatively high mileages.

An interesting relationship is depicted by Figure 10 which shows the analysis for exhaust hydrocarbon emissions from 1973 model year cars. Here the linear model shows a decreasing emission rate trend with increasing miles, whereas the logarithmic model shows the normally expected, albeit very modest, increase in HC emission rate with miles.

As with the prior discussion of the 1975 model year data analysis, the correlation of the emission data with miles is very poor whether the linear or the logarithmic model is chosen. Correlation coefficients for these 21 data sets vary from .006 to .327. In some cases, the logarithmic model displays slightly better correlation coefficients whereas in other cases the linear model appears to be a better fit. While MVMA does not consider the "score" significant, the logarithmic model shows a better correlation for 12 out of these 21 data sets.

We believe these limited analyses of a portion of the data, which is indicated to support the emission factors for the 1968 through 1974 model years, strongly suggest that those emission factors overstate the emission rates, particulary for HC and CO at high mileages. We therefore urge the EPA to re-analyze the total body of Emission Factor Surveillance data considering alternates to the linear model which could provide a significantly improved expression of the emission factors as a function of miles.

Controlled Evaporative Emissions

Table 2-12 of EPA's Interim Document indicates evaporative emission rates for controlled light duty gasoline powered vehicles to be 1.76 g/mi for 1971 through 1977 cars, and .60 g/mi for 1978 and 1979 vehicles. The value stated for the first generation of evaporative controls (though 1977) appears to be incorrect. That rate errs on the high side because of reliance on a single data body which apparently involves erroneous measurements. In addition, there is the less serious but still important controversy over conversion of the regulatory gram per test basis for expressing evaporative emissions to the g/mi basis as discussed earlier. The 1.76 g/mi value would become 2.05 g/mi under the MIT method (Reference 5).

The Interim Document emission factors are based on data from EPA's Emission Factors Surveillance Programs, primarily the FY 71 program (Reference 9). The indicated emission levels from first generation controlled cars (1971 through present) appear excessively high. Table 5 compares similar data from three separate independent programs with the FY 71 data. The independent data referenced in that Table indicate that the EPA Emission Factor Surveillance Program measurements of 24-27 grams per test are high by more than a factor of 2. The

California Air Resources Board (CARB) program involves several times more in-use cars than did the EPA program. Furthermore, the CARB program was begun in calendar year 1975 and benefitted by the mistakes made in the earlier EPA programs.

These high values obtained in the EPA surveillance programs have not been explained. However, from available information it appears probable that installing the fuel tank thermocouple through the fuel tank cap may have resulted in vapor leaks. This assumption may explain both the larger discrepancy of the diurnal soak values (diurnal soak emissions are virtually 100% tank emissions) and the agreement of the FY 71 results from uncontrolled cars with the previously accepted values. Such a vapor leak would not affect emissions from uncontrolled vehicle tanks which are already vented to atmosphere.

Another possible explanation for the high emissions from the FY 71 program is the difficulty of proper placement of the tank fuel thermocouple with the lead-through-the-cap approach. With that approach the thermocouple junction can easily lodge in the fill pipe or the tank vapor space. Attempts to drive the resulting vapor temperature, rather than the intended liquid temperature, through the prescribed excursion by heating the tank liquid, results in unrealistically high emissions.

A weighted average of the data from the first three test programs of Table 5 yields 7.4 g/test as representative of the first generation of emission controls. Similar treatment of the modal values yields .81 g/mi by the MIT method (i.e., 1.8 g diurnal and 5.6 g hot soak). The 1978 6 g/test standard, on the other hand, assuming a 1.5/4.5 gram diurnal soak to hot soak distribution results in .65 g/mi.

Truck Exhaust Emission Factors

The subject of truck emission factors is so complex that an attempt will not be made to provide a detailed treatment in this paper. However, a few brief comments are in order since there are serious questions about the validity of the truck emission factors contained in the Interim Document.

Actually, there are three discrete populations - the light duty vehicle (less than 6000 lbs. GVW), the intermediate truck (6001-8500 GVW), and the heavy duty truck (over 8500 lbs. GVW).

Because of differences in driving patterns, load factors, N/V ratio, weight/power ratio and other factors, the use of passenger car deterioration rates to the intermediate class of vehicles cannot be justified. The intermediate vehicle will not be subjected to a chassis dynamometer certification test until the 1979 model year, so there is almost a total absence of vehicle data to provide an uncontrolled baseline.

The heavy duty truck is not subjected to certification testing. In this category, the engine is tested and certified. A separate MVMA panel is currently engaged in a project to develop factual heavy duty engine baselines. As with the intermediate vehicle, the extensive data and deterioration rates determined for passenger cars and intermediate trucks to the heavy truck category cannot be justified. Data are simply not interchangeable between the three populations.

As an example, our concern over the validity of the truck data, Table 3-1 of the Interim Document shows higher than precontrol carbon monoxide emissions for the 1970-78 model year trucks (6001 to 8500 lbs. GVW). By contrast, an analysis of the test results from the same program, as shown in Figure 11 (Reference 15), indicates more than a 60% control of

CO from 1972-73 trucks. This discrepancy between two analyses is not explained. Figure 11 also raises a similar question on exhaust hydrocarbon emissions. In the case of hydrocarbons, the new vehicle emission rates of Figure 3-1 indicate a control of about 33%, whereas, the data in Figure 11 suggests control of more than 50%.

It is further indicated in the Interim Document that the average age of the uncontrolled 6001-8500 lbs. GVW trucks used in the program was seven years and that the new truck emission factor was extrapolated back from the deterioration rate of precontrolled passenger cars. In view of our earlier comments on passenger car deterioration rates, the application of these deterioration rates to a completely different class of vehicles is unjustified.

Summary

The following summarizes the major conclusions of this paper:

- Emission factor data in AP-42 are based on the 1975 FTP cycle used for U.S. certification. In applying such data the user should first check to see if this cycle is applicable to his analysis. If not, appropriate adjustments should be made.
- Emission levels from uncontrolled cars was found to vary with model year. Model year 1960 was selected as the uncontrolled "benchmark". Uncontrolled emissions from 1960 model year passenger cars were found to be 19 g/mi HC (10.6 exhaust, 4.3 evaporative and 4.1 crankcase), 84 g/mi CO and 4.1 g/mi NOx.
- The AP-42 uncontrolled CO emission rate of 124.8 g/mi for 1960 cars driven in calendar year 1970 appears to be excessively high. Better documentation of the basis for AP-42 emission numbers is needed.
- The AP-42 evaporative emission rate for uncontrolled cars errs on the low side as a result of neglecting fuel tank running losses.

- It is recommended that the regulatory evaporative test-to-g/mi emission rate conversion be based on the MIT method (Reference 5).
- Emission factors in AP-42 for controlled vehicle exhaust emissions reflect extremely high additive deterioration rates extrapolated beyond the set of data used to estimate these rates. It is recommended that some credit be given to the activity by both manufacturer and regulator to reduce the probability and magnitude for high deterioration in future vehicles.
- Controlled evaporative emissions for the first generation of emission controls are estimated to be 0.81 g/mi. The AP-42 appears to be excessively high (1.76 g/mi).
- Trucks of different Gross Vehicle Weights have been categorized as light, medium and heavy duty. All of these categories have emission related characteristics different than passenger cars. The application by EPA of passenger car emission deterioration rates

and other characteristics to these vehicles is therefore inapproriate and appears to have resulted in substantial understatement of current levels of control.

REFERENCES

1. "Mobile Source Emission Factors," EPA Interim Document, OTLUP, Washington, D.C., June, 1977.

2. Seventh Annual Report to the President's Council on Environmental Quality, 1976.

3. R. L. Kramer and H. P. Cernansky, "Motor Vehicle Emission Rates," U.S. Department of Health, Education and Welfare, Durham, N.C., August 15, 1970.

4. J.C. Gagliardi and F.E. Ghannam, "Effects of Tetraethyl Lead Concentration on Exhaust Emissions in Customer Type Vehicle Operation," SAE 690015, January, 1969.

5. John B. Heywood, "Statement to the Subcommittee on Public Health and Environment," Interstate and Foreign Commerce Committee, U.S. House of Representatives, Washington, D.C. December 4, 1973.

6. D.T. Wade, "Factors Influencing Vehicle Evaporative Emissions," Society of Automotive Engineers Paper No. 670126, January, 1967.

7. "Fuel System Evaporative Losses," issued by the Automobile Manufacturers Association, AMA Engineering Notes 616, September, 1961.

8. S.W. Martens and E.E. Nelson, "Current Status of Vehicle Evaporative Emission Control," presented at Fourth Annual North American Motor Vehicle Emissions Control Conference, Anaheim, California, November 5, 1975.

9. CALSPAN Corporation, "Automobile Exhaust Emission Surveillance - A Summary," Document No. APTD-1544, prepared for Environmental Protection Agency, Office of Air and Water Programs, Office of Mobile Source Air Pollution Control, Ann Arbor, Michigan, May, 1973.

10. "Automobile Exhaust Emission Surveillance Analysis of the FY 1974 Program," EPA-460/3-76-019.

11. "Exhaust Emissions from Privately Owned 1966-1973 California Automobiles, A Statistical Evaluation of Surveillance Data," Supplement of Progress Report No. 34, Surveillance of Motor Vehicle Emissions in California, California Air Resources Laboratory, El Monte, California, May 1974.

12. Statement of General Motors Corporation to EPA - Waiver Hearing on Adjustability of Idle Mixture Mechanism, San Francisco, California, May 18, 1977.

13. State of California Air Resources Board "California Exhaust Emission Standards and Test Procedures for 1980 and Subsequent Model Passenger Cars, Light Duty Trucks, and Medium Duty Vehicles" - Adopted November 23, 1976, amended June 22, 1977.

14. "New Motor Vehicle Certification, Intent to Develop Rulemaking," EPA, Federal Register, Volume 42, No. 104, May 31, 1977.

15. "Historical Development of Heavy Duty Gasoline Engine Dynamometer Emissions Test Cycle and Emissions Standards," Motor Vehicle Manufacturers Association, Detroit, Michigan.

16. "Los Angeles Auto Exhaust Test Station Project - A Joint Agency Report, 1961-1963", Air Pollution Control District, County of Los Angeles, California, Automobile Club of Southern California, Automobile Manufacturers Association, Detroit, Michigan California Department of Public Health, California Motor Vehicle Pollution Control Board, California Highway Patrol, United States Public Health Service.

17. "Baseline Reactivity Survey," California Air Resources Board, Los Angeles, California, February, 1968.

18. "Surveillance of Motor Vehicle Emissions in California, Quarterly Progress Report No. 15, January-March, 1969", California Air Resources Board, Los Angeles, California.

19. "A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions," CRC-APRAC Project CAPE-13-68 and EPA by TRW and Scott Research Laboratories, July, 1973.

20. D.W. Houser, R.F. Irwin, L.J. Painter, G.H. Amberg, "Field Tests Show Gasoline Deposit Control Additives Effective in Emission Reduction," APCA Meeting June, 1971.

21. The Great Plains Surveillance Program, FY 69.

22. The National Surveillance Program -- Phase I, FY 70.

23. The National Surveillance Program -- Phase II, FY 70.

24. Marcia E. Williams, John T. White, Lois A. Platte, Charles J. Domke, "Automotive Exhaust Emission Surveillance - Analysis of the FY 72 Program," EPA - 460/2-74-001, U.S. Environmental Protection Agency, Ann Arbor, Michigan, February, 1974.

25. Jeffrey Bernard, Paul Donovan, H.T. McAdams, "Automobile Exhaust Emission Surveillance Analysis of the FY 73 Program," EPA - 460/3-75-007, Prepared by CALSPAN CORPORATION for the U.S. Environmental Protection Agency, Ann Arbor, Michigan, July, 1975.

26. H.A. Ashby, R.C. Stahman, B. H. Eccleston, R.W. Hurn, "Vehicle Emissions - Summer to Winter," Society of Automotive Engineers Paper No. 741053, Presented at Toronto, Ontario, Canada, October, 1974.

27. Study of Emissions from Light-Duty Vehicles in Seven Cities, FY 75 (unpublished).

28. P.J. Clarke, "Investigation and Assessment of Light Duty Vehicle Evaporative Emission Sources and Control," Document No. EPA-460/3-76-014, prepared for Environmental Protection Agency, Office of Air and Waste Management, Office of Mobile Source Air Pollution Control, Ann Arbor, Michigan, June, 1976.

29. T.M. Fisher, Letter to Eric O. Stork of the U.S. Environmental Protection Agency, General Motors Corporation Warren, Michigan, May 14, 1976.

30. "Surveillance of Evaporative Emissions from 1970 to 1976 Year Model Vehicles by the SHED Method," Project E. Progress Report No. 5, Air Resources Board, 9528 Telstar Avenue, El Monte, California, March, 1976.

31. California Department of Public Health, Progress Report - Motor Vehicle Emissions and Proposed Standards, January 8, 1964.

32. Thomas A. Huls, "Evolution of Federal Light Duty Mass Emission Regulations," Society of Automotive Engineers paper 730554, presented at the Automobile Engineering Meeting, Detroit, Michigan, May 1973.

33. S.H. Mick and J.B. Clark, Jr., "Weighing Automotive Exhaust Emissions," Society of Automotive Engineers paper 690523, May 1969.

34. "California Test Procedure and Criteria for Motor Vehicle Exhaust Emission Control," State of California, Motor Vehicle Pollution Control Board, January 23, 1964.

35. "1975 Emission Standards for Hydrocarbons and Carbon Monoxide Applicable to Light Duty Vehicles," Notice of Proposed Rulemaking, U.S. EPA, Federal Register, Vol. 36, No. 39, February 26, 1971.

36. "Exhaust Emission Standards and Test Procedures", U.S. EPA, Federal Register, Vol. 36, No. 128, July 2, 1972.

37. A.J. Hocker, "Summary of Oxides of Nitrogen Test Methods and Test Data," California Air Resources Board, Los Angeles, California, May 26, 1969.

TABLE I

Exhaust Emission Data on 1965 and Older Vehicles

Source	Year Completed	Number of Vehicles 1965 and Older	Driving Cycle	Reference Number
1962 California Program	1962	1000	Hot 8-Mode	16
Baseline Reactivity Survey	1968	212	Hot 7-Mode	17
CARB Study	1969	12*	Hot 7-Mode	18
Rose Bowl Study	1971	161	7-Mode	20
EPA FY 71 Program by AESI**	1973	337	1975 FTP	9
CRC - Maintenance Study	1973	--	1972 FTP	19

---

* Includes HC and CO data only for a substantially larger number of 1965 cars.

** FY 71 program included uncontrolled 1966/67 49 state cars.

TABLE 2

Uncontrolled Automotive Exhaust Emissions

Model Year	Mean Line Exhaust Emissions g/mi (1975 FTP) HC	CO	NO_x
1947	16.6	108	2.8
1948	15.9	105	2.9
1949	15.3	102	3.1
1950	14.7	100	3.3
1951	14.1	97	3.4
1952	13.6	95	3.5
1953	13.1	93	3.7
1954	12.6	91	3.8
1955	12.2	90	3.9
1956	11.8	88	3.9
1957	11.4	87	4.0
1958	11.1	86	4.1
1959	10.8	85	4.1
1960	10.6	84	4.1
1961	10.4	84	4.1
1962	10.2	83	4.1
1963	10.1	83	4.1
1964	10.0	83	4.1
1965	9.9	84	4.1

TABLE 3

In-Use Exhaust Emission Data on Controlled Vehicles

Source	Model Years	Number of Vehicles	Driving Cycle	Evap. Emissions	Reference Number
CRC Vehicle Emission Tests	1967-1968	188	7-mode		*
EPA FY 69	1968-1969	2029	7-mode	No	21
EPA FY 70-I	1970	2101	7-mode	No	22
EPA FY 70-II	1971	369	7-mode	No	23
EPA FY 71	1957-1971	1020	1972/1975 FTP	Yes	8
CRC Maintenance Study	1960-1971	486	1972 FTP, loaded mode-idle		18
EPA FY 72	1966-1972	1020	1972/1975 FTP	Yes	24
EPA FY 73	1967-1974	1080	1972/1975 FTP, short tests, and modal	Yes	25
	1967-1975	26	1975 FTP	No	26
EPA FY 74	1965-1975	1968	1974 FTP, HWFET, short tests, and modal	No	9
EPA FY 75	1968-1976	2220	1975 FTP, HWFET, short tests, and modal		27

---

* Unpublished data generated in the program summarized in Reference 19

TABLE 4

Evaporative Emissions from In-Use Cars Measured by the SHED Techniques

Laboratory	Model Year	Number of Cars	Mean Emission Total g/test	Diurnal Soak g	Hot Soak g	Reference
Exxon	1973-75	20	8.99*	1.6*	7.9*	28
GM	1970-72	20	8.7	3.37	5.36	29
CARB	1970-76	109	6.9	1.5	5.4	30
AESI(FY 71)	1970-71	31	27.2	16.28	10.92	8

---

* Exxon data uncorrected for non-fuel background emissions, modal average based on 18 of the 20 test cars.

FIGURE 1

UNCONTROLLED AUTOMOTIVE HC

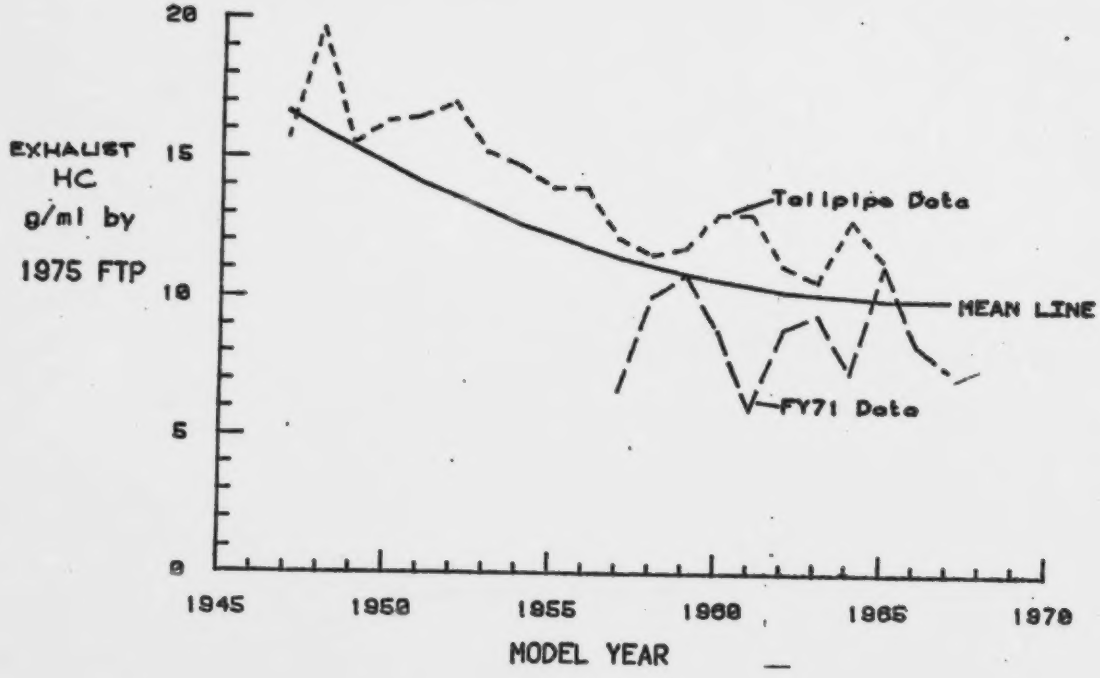


FIGURE 2

UNCONTROLLED AUTOMOTIVE CO

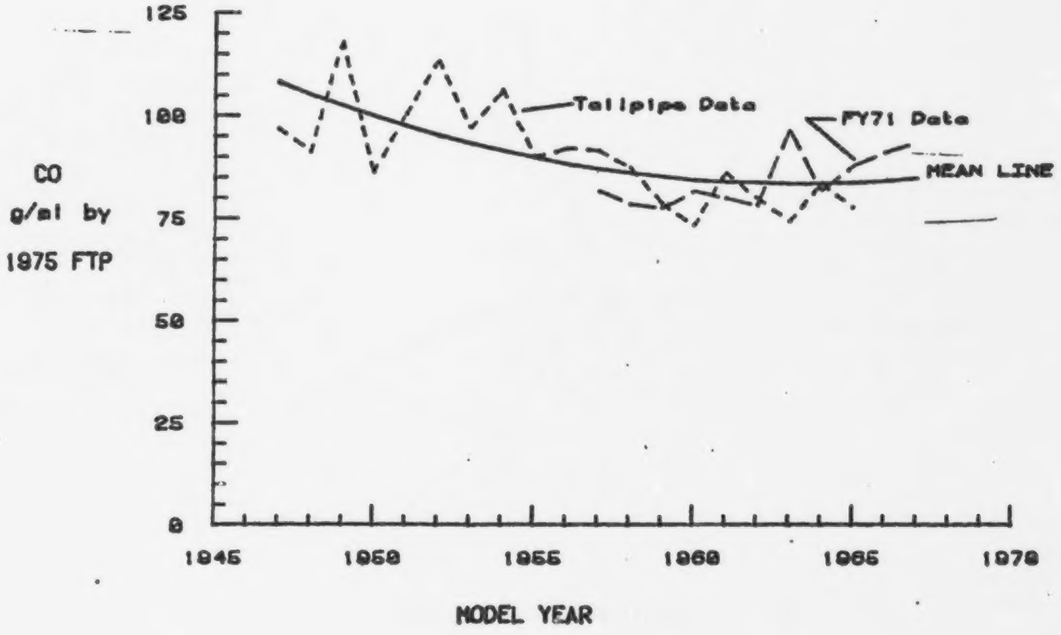


FIGURE 3

UNCONTROLLED AUTOMOTIVE NOx

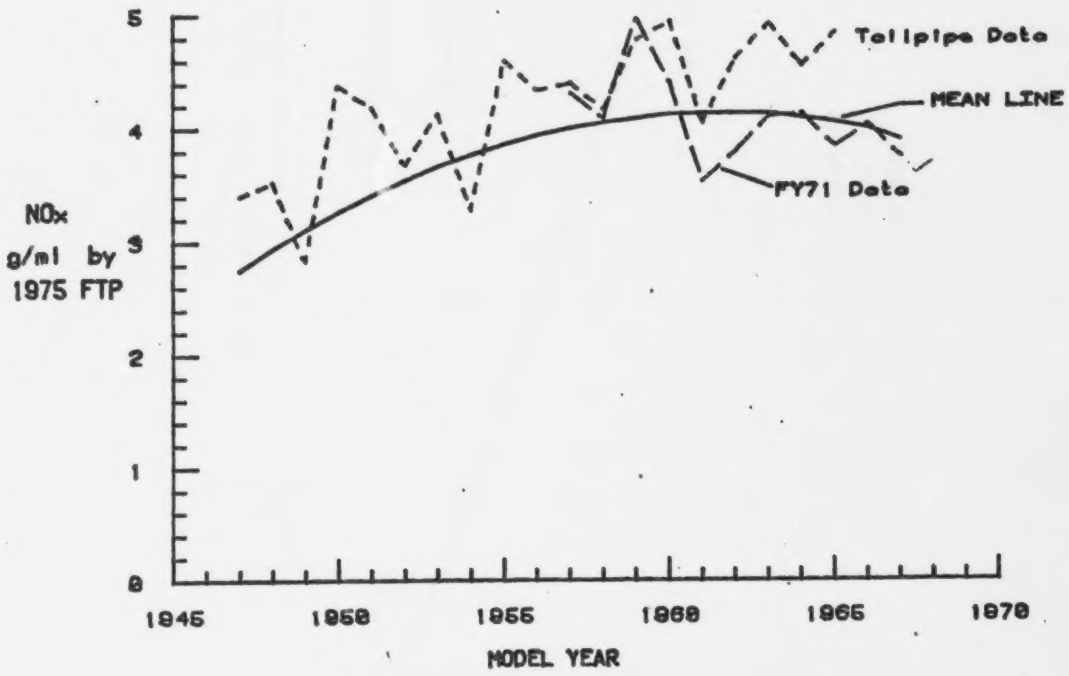


FIGURE 4

LDV EMISSION RATES

MODEL YEAR 1975

EXHAUST HYDROCARBONS

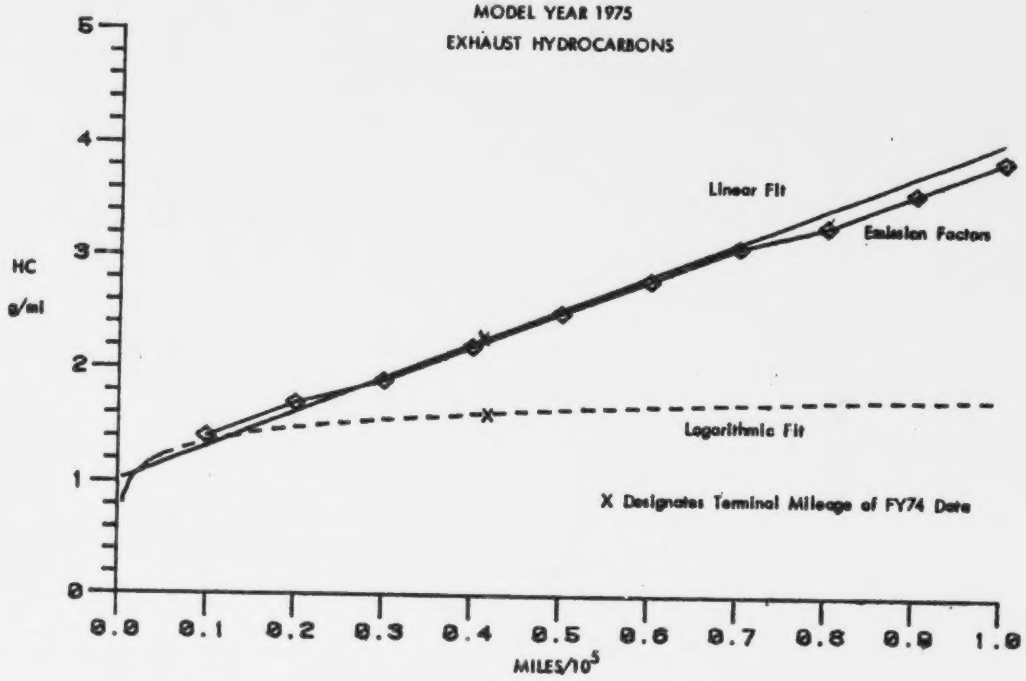


FIGURE 5
LDV EMISSION RATES
MODEL YEAR 1975
CARBON MONOXIDE

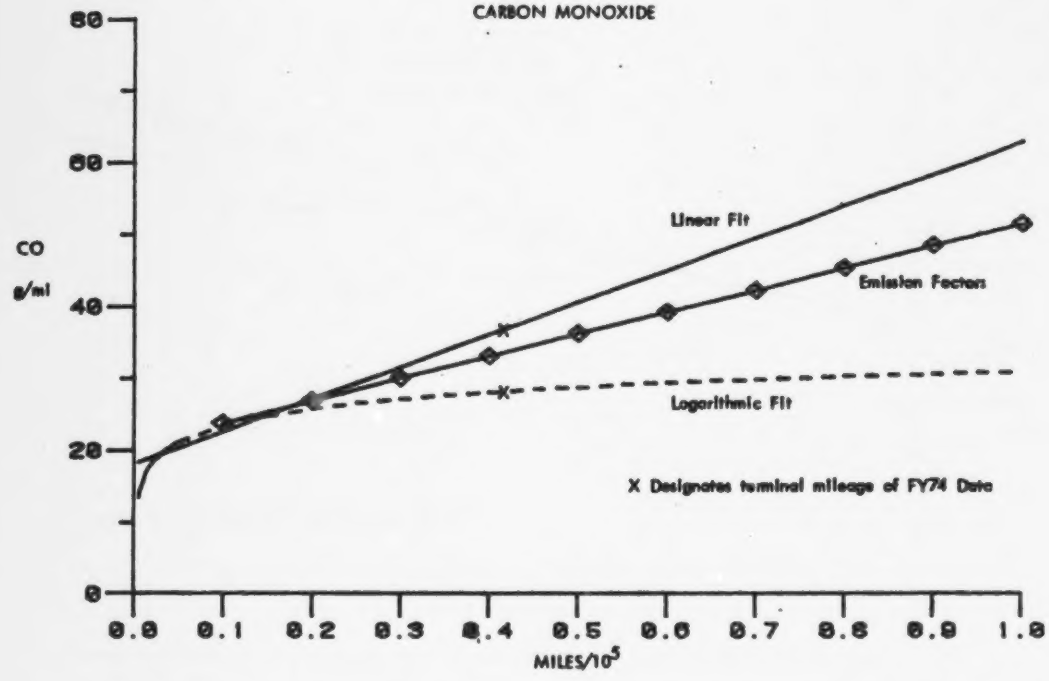


FIGURE 6

LDV EMISSION RATES

MODEL YEAR 1975

OXIDES OF NITROGEN

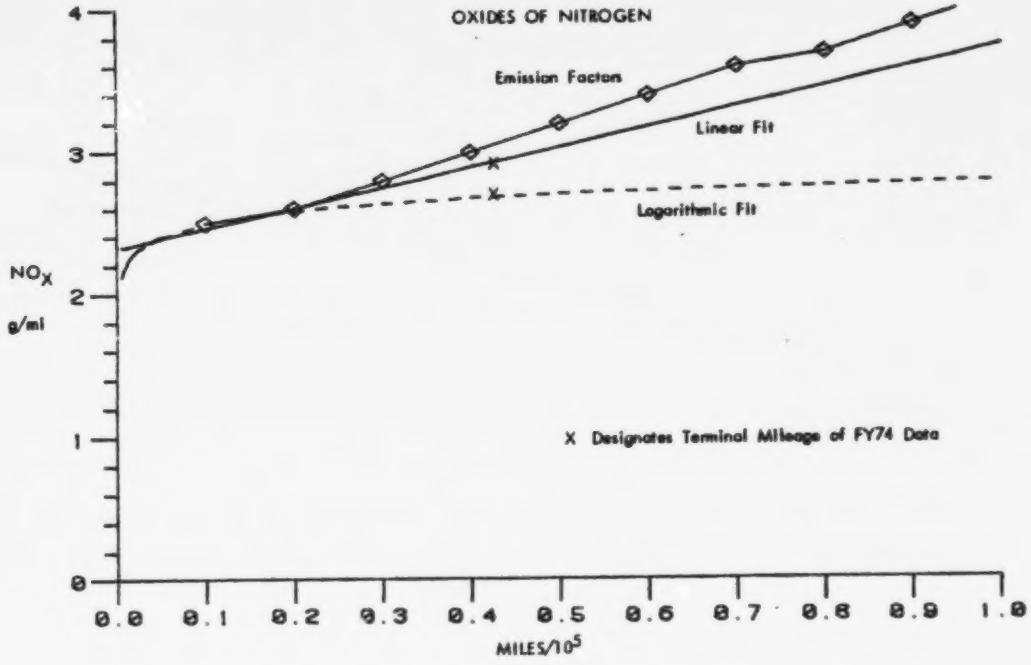
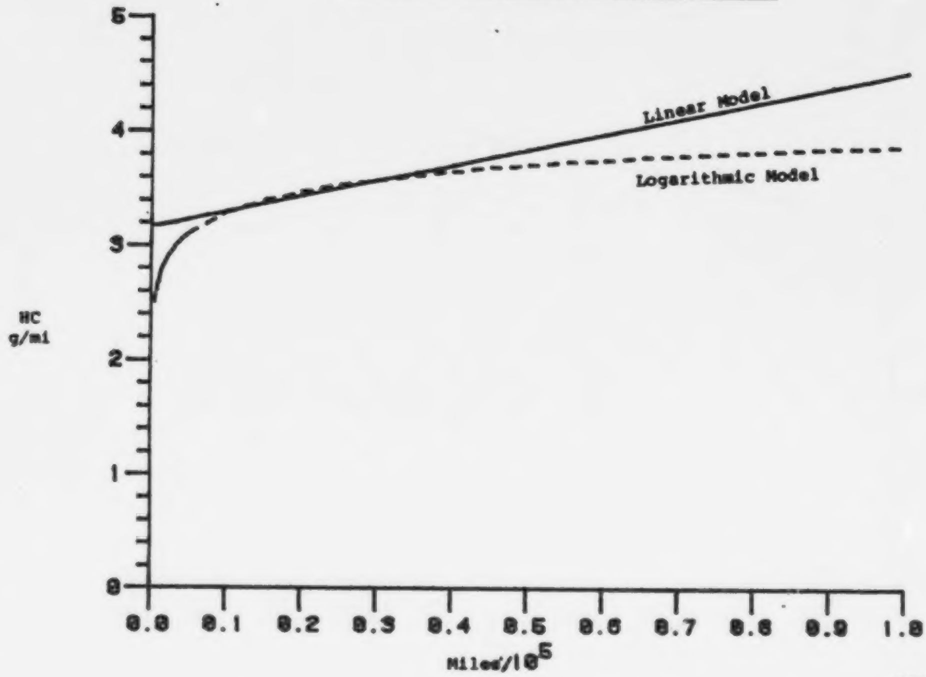


FIGURE 7

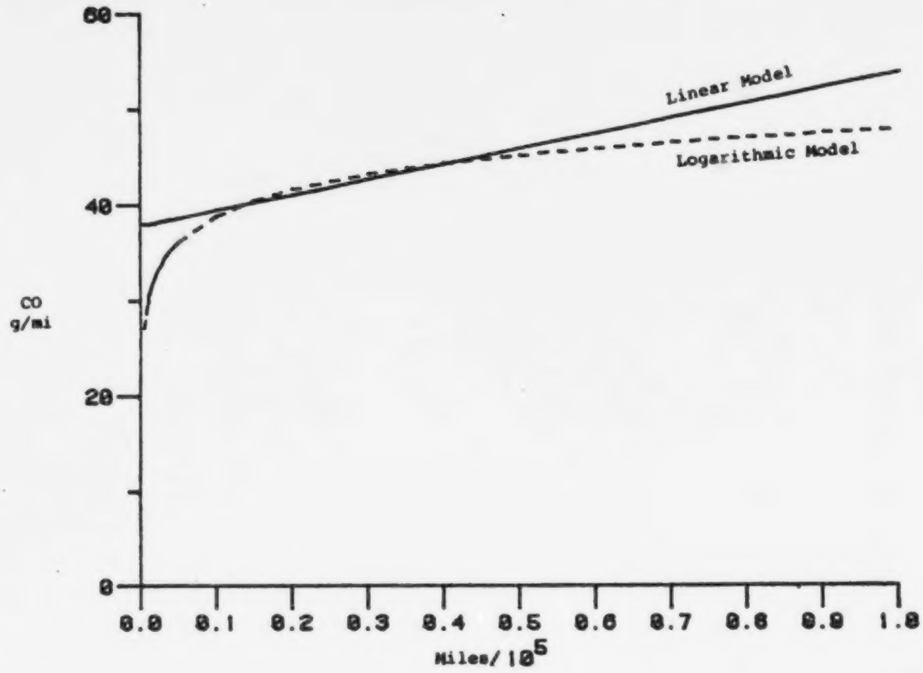
Automotive Exhaust HC Emission Levels
Fits of FY 74 Data
1974 Models



HC74/HC74A

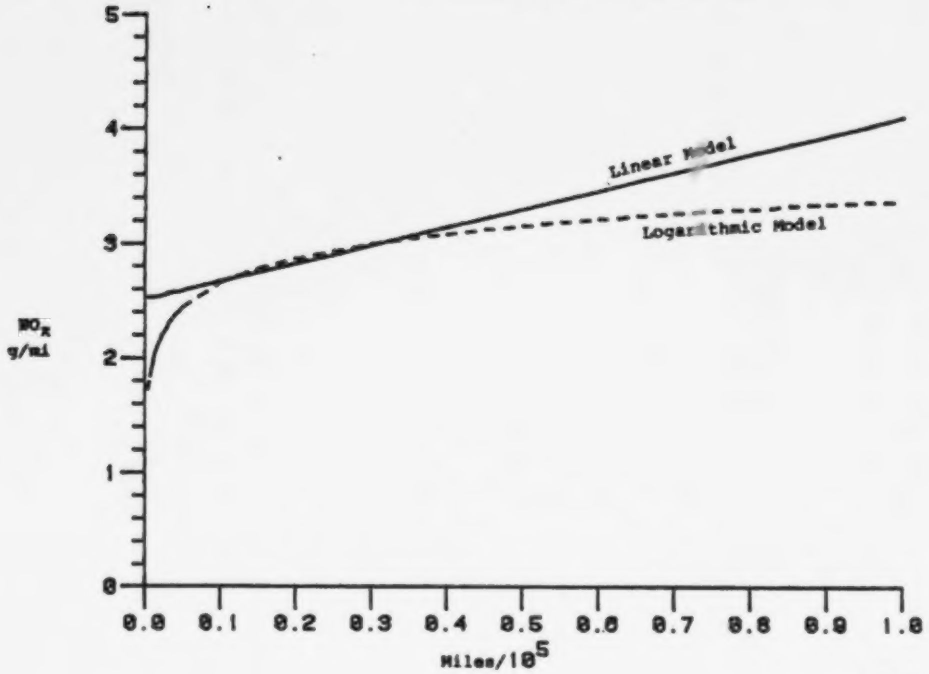
FIGURE 8

Automotive CO Emission Levels
Fits of FY 74 Data
1974 Models



CO74/CO74A

FIGURE 9
Automotive NO_x Emission Levels
Fits of FY 74 Data
1974 Models



NOX74/NOX74A

FIGURE 10

Automotive Exhaust HC Emission Levels
Fits of FY 74 Data
1973 Models

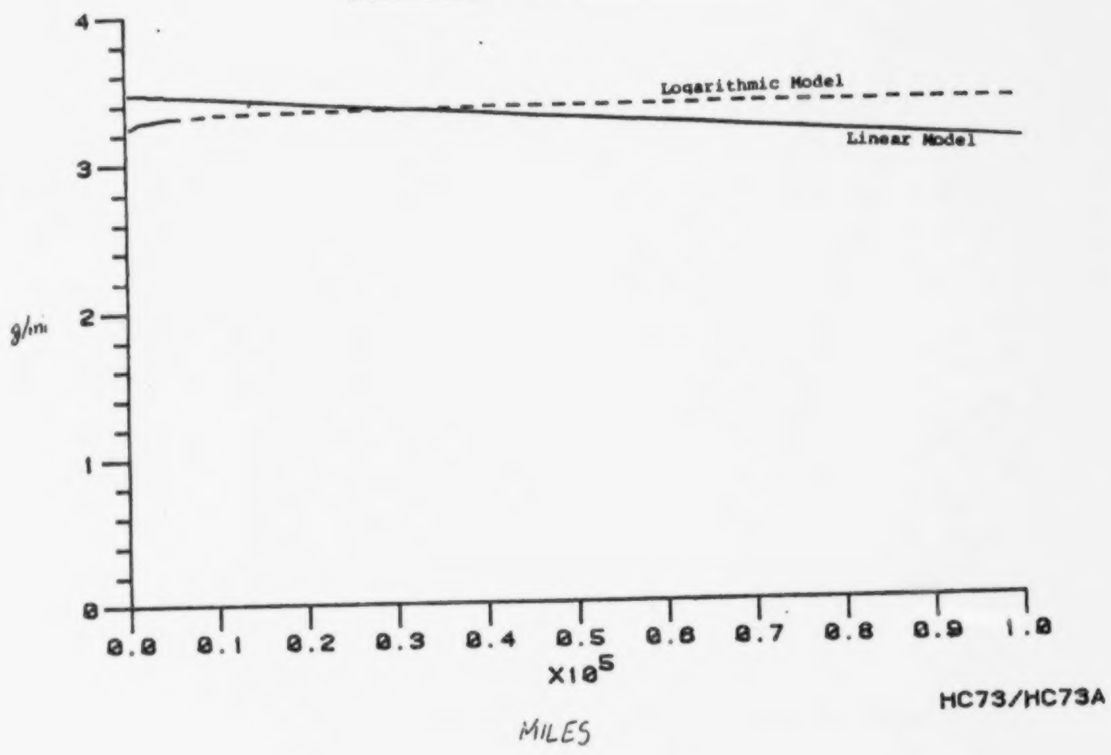
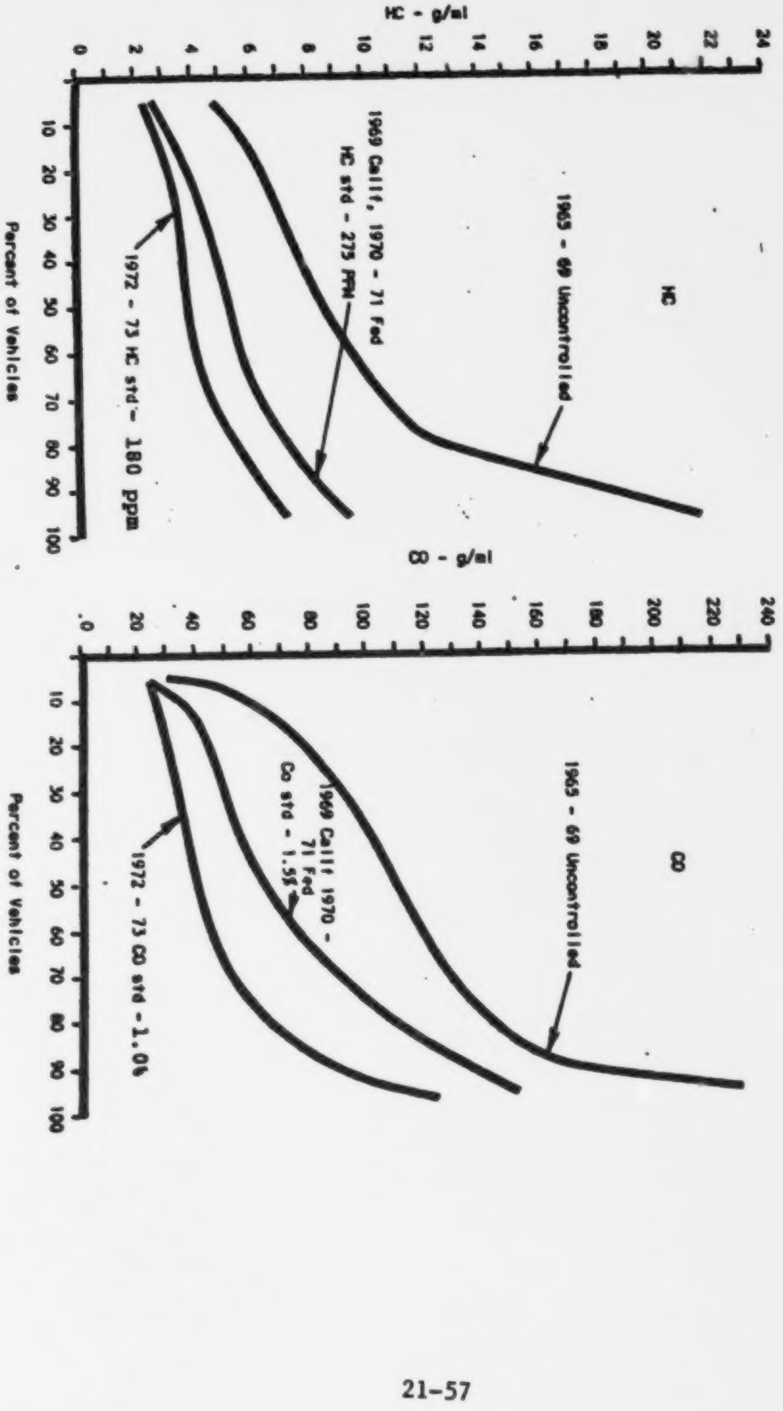


FIGURE 11

H. D. Vehicle Emission Performance - 5000 lbs Inertia Weight Category - EPA Study of Baseline Emissions of 1965-1973 6000 - 14,000 lbs GVW Trucks



APPENDIX

Uncontrolled Car
Exhaust Emission Data
and
Their Adjustment

Huls formally published in 1973 (Reference 32) the EPA development of uncontrolled car baseline exhaust HC and CO values for the 1972 Federal Test Procedure (FTP). The 1972 FTP and its successor, the 1975 FTP, obtain a direct mass rate of emissions by diluting the vehicle exhaust stream (with air) to a constant fixed flow rate and measuring the pollutant concentrations in that stream--hence the term Constant Volume Sampler (CVS); see for example Reference 33. Huls' values, 16.8 g/mi HC and 126 g/mi CO were obtained by correcting a large bank of 7-mode (Reference 34) and similar tailpipe test data to the CVS procedure via empirical factors developed from tests of 30 uncontrolled cars. These values further adjusted to 15 g/mi HC and 90 g/mi CO when a correction was made for the "cold/hot weighted" 1975 FTP--References 35 and 36 list "statutory" HC/CO standards of .46/4.7 and .41/3.4 based on the 1972 FTP and the 1975 FTP respectively. The HC and CO 1975 FTP/1972 FTP corrections are therefore .891 and .723.

At about the same time as the Huls' publication, EPA released results of a field survey in which customer cars were actually directly tested using the CVS method and included a substantial number of uncontrolled cars (Reference 9). Data from those uncontrolled cars averaged 8.7 g/mi exhaust HC and 87 g/mi CO over the 1975 FTP. This latter exhaust HC level represents a very large discrepancy compared to the above 15 g/mi value. We are aware of no previous attempt to rationalize the difference between these two sets of "baseline" values.

It seems apparent to us from the plot of the two bodies of data in Figure 1 that the major difference in the two "baselines" is the model year make up of the two car populations involved. Although to our knowledge EPA has never formally published the sources of the data body which made up the 7-mode cycle baseline values, we believe that the HC data we have assembled from the literature represents essentially all that is available and therefore must be roughly equivalent to the data body used by Huls.

Note in Figure 1 that the so-called tailpipe data (primarily 7-mode cycle data) have been corrected to the 1975 FTP basis. Table A-1 details the actual tailpipe data from the various surveys together with the corresponding 1975 FTP value. In addition, it lists the weighted average of the latter values which were used to form the "tailpipe data" plot of Figure 1.

Huls showed that the average car over the 7-mode cycle, at the 2.2 g/mi HC standard of 1970, would have a composite concentration value of 180 ppm. Consequently, the correction factor from composite tailpipe concentration values to 1970 FTP g/mi values is .0122. This value is then adjusted to the 1972 FTP by a multiplying correction factor according to Huls of 1.38, and in turn by a factor of 0.891 as indicated above to correct to the 1975 FTP. It is shown in Reference 31 that the average car tested on the cold start 7-mode cycle (1970 FTP) produced HC values 1.101 times that of the hot7-mode cycle. All of the concentration data as indicated on Table A-1 were based on test from a hot start because of the practical problems of testing very large numbers of cars. In addition, Reference 30 details the basis for an adjustment factor of 1.212 to the 8-mode cycle hot start HC concentrations of the Los Angeles Test Station Project (Reference 16). Thus, the latter data have been corrected to the 1975 FTP basis through multiplication by correction factors of 1.212 x .0122 x 1.38 x .891. The Baseline Reactivity survey (Reference 17) and the 194 Car Survey data were corrected to 1975 FTP by a multiplicitive correction factor of 1.101 x .0122 x 1.38 x .891. Finally the Rose Bowl survey performed on the 1970 FTP basis was corrected simply by multiplication of 1.101 x 1.38 x .891.

While it is obvious from Figure 1 that the direct 1975 FTP measurements of the FY 1971 program are similar to the older tailpipe data for the same model years, there does remain a small discrepancy. Since we have no basis to choose one set of values over the other, we have assumed in Table A-2, whose values generated the mean line of Figure 1, that the true value for the average emission rate of the "overlapping" model years is midway between the corrected tailpipe values and the FY 71 values. To be specific, the corrected data of Table A-2 were obtained by averaging the 1957 through 1965 values from both data bodies, and adjusting the tailpipe data downward by half the difference and the FY 71 data upward by half the difference. The mean line of Figure 1 then is a least-squares fit of a second degree polynomial to that corrected data.

The carbon monoxide tailpipe data of Table A-3 were similarly obtained from the correction factors of Huls--23.0 from tailpipe concentrations to 1970 FTP g/mi and 1.58 from 1970 FTP to 1972 FTP and from References 35 and 36 the adjustment from 1972 FTP to 1975 FTP for carbon monoxide is .723. Reference 31 indicates that the tailpipe carbon monoxide values for uncontrolled cars from hot start compared with cold start were not significantly different and consequently no hot start to cold corrections factor is required. Similarly, Reference 31 further states that the test cycle and other corrections made to the Los Angeles Test Station HC data are unnecessary for carbon monoxide. Consequently, the tailpipe concentration CO data for the Los Angeles Test Station Project, the Baseline Reactivity Survey and the 194 Car Survey have been corrected to the 1975 FTP by multiplication of 23.0 x 1.58 x .723. The Rose Bowl Survey data, on the other hand, were simply corrected by adjustment from the 1970 FTP to the 1975 FTP, i.e., by a multiplication of 1.58 x .723.

Analogous to Table A-2, the data detailed in Table A-4 show the adjustment made to the tailpipe CO data and the FY 71 1975 FTP data to a common 1957-1965 average value. The latter finally resulted in the mean line of Figure 2 which is, similar to the HC mean line of Figure 1, a least-squares second degree polynomial fit of the Table A-4 data.

Published documentation for conversion of tailpipe concentration NOx data from one test type to another and from the tailpipe to the CVS basis is less complete than the foregoing conversion procedures for exhaust HC and CO. As far as we are aware, there has been no publication of back-to-back 1970 FTP measurements versus 1975 FTP measurements for NOx--of the type described by Huls for HC and CO. However, the conversions used for Table A-5 require such relationship.

An experimental program was conducted by General Motors using 27 pre-1968 cars. That test program, which involves back-to-back tests on the 1970 FTP and the 1972 (CVS) FTP, is summarized in Table A-7. The indicated weighting of those "equivalence ratios" for a realistic distribution of the cars in the population of the early 1960's (by manufacturer) is indicated to produce a correction factor of 1.082. As indicated on Table A-7 References 35 and 36 indicate that this conversion factor should be in turn multiplied by the ratio 3.1/3.0 to result in the final correction factor of 1.118 to obtain 1975 FTP values from 1970 FTP data.

Analogous to the previously described relationship developed by Huls for converting tailpipe concentration values to 1970 FTP g/mile values for HC and CO, the NOx tailpipe concentration from the average car should be multiplied by the factor .0037 to obtain the 1970 FTP value. Reference 31 indicates that there is not an appropriate correction factor for converting the 8-mode cycle tailpipe concentration values of the Test Station Project, nor the hot start test to the 1970 FTP basis. Consequently, these values have been assumed to be related to 1970 FTP values by a factor of 1.

The Test Station Project tailpipe NOx concentration values have consequently been multiplied by an overall correction factor of .0037 x 1.118 x 3.1/3.0 to convert to the 1975 FTP g/mile basis. It was necessary, in addition, to divide the resulting values for the Baseline Reactivity Survey data by 1.5 since those NOx data were obtained by "bagging" the entire exhaust of the 7-mode cycle which includes some normally unsampled heavy load operation (Reference 37). The Rose Bowl survey, on the other hand, which is originally given in 1970 FTP g/mile, has simply been multiplied by 1.118 x 3.1/3.0.

As a final note, it is well to acknowledge that the tailpipe data used in these analyses does not include the "CARB Study" (Reference 18) included in Table I. As indicated in Table I, only 12 of the 1965 test cars involved NOx measurements. Furthermore, the only other model years accounted for by that "study" were 1966 and 1967. Exhaust controls were required for both those model years in California. We understand that the 1966/67 cars considered "uncontrolled" in that program were "imports" from outside the state. Nonetheless, their inclusion raise questions for which satisfactory documentation is unavailable. Consideration of those questions, and the fact that a single model year from one test program could unduly influence the "shape" of the final emissions--vs.--model year relationship, led us to reject the "CARB Study" data for this analysis.

Table A-1

Exhaust HC Tailpipe Measurements from Uncontrolled Cars

	Los Angeles Test Station Project[16]			Reactivity Survey[17]			1974 Car Survey[31]			Rose Bowl Survey[20]			Weighted Average
Model Year	N	Conc., ppm	1975 FTP, g/mi	N	Conc., ppm	1975 FTP, g/mi	N	Conc., ppm	1975 FTP, g/mi	N	1970 FTP, g/mi	1975 FTP, g/mi	1975 FTP, g/mi
1947	4	862	15.7	-	-	-	-	-	-				15.7
1948	6	1148	20.9	-	-	-	2	957	15.8				19.6
1949	7	918	16.8	1	795	13.1	5	854	14.1				15.5
1950	23	896	16.1	-	-	-	8	1028	17.0				16.3
1951	25	932	16.9	-	-	-	13	951	15.7				16.5
1952	16	900	16.5	-	-	-	9	1083	17.9				17.0
1953	39	832	15.2	2	987	16.3	12	914	15.1				15.2
1954	50	805	14.7	2	841	13.9	13	900	14.9				14.7
1955	89	780	14.2	1	617	10.2	26	774	12.8				13.9
1956	100	732	13.4	1	509	8.4	22	1008	16.7				13.9
1957	112	629	11.4	6	834	13.8	15	1005	16.6	-	-	-	12.1
1958	72	625	11.3	5	912	15.1	11	732	12.1	5	7.00	9.5	11.5
1959	109	657	11.9	6	635	10.5	17	718	11.9	3	6.52	8.8	11.8
1960	109	646	11.8	9	1987	32.8	16	757	12.5	12	6.94	9.4	13.0
1961	108	731	13.4	16	942	15.6	19	751	12.4	14	5.93	8.0	13.0
1962	151	635	11.5	21	711	11.7	-	-	-	24	6.06	8.2	11.1
1963	13	563	10.3	51	628	10.4	-	-	-	30	8.15	11.0	10.6
1964	-	-	-	45	937	15.5	-	-	-	38	7.14	9.7	12.8
1965	-	-	-	46	763	12.6	-	-	-	35	7.21	9.7	11.3

Notes
- o Superscripts on each survey title indicate associated reference number.
- o N = Number of cars tested.
- o LA Test Station data were obtained using an 8-mode cycle--from hot start.
- o Reactivity Survey data were obtained using the 7-mode cycle--from hot start.
- o 194 Car Survey data were obtained via weighted 7-mode/11-mode cycle--from hot start. (Listed reference includes only summary data, details obtained from raw data.)
- o Rose Bowl Survey data were obtained using 1970 FTP--except tests run from hot start.

Table A-2

Exhaust HC Measurements from Uncontrolled Cars

Adjusted Data

All data are 1975 FTP g/mi

Model Year	Wtd. Avg. Tailpipe Data From Table A-1	FY 71 CVS Data From Ref. 9	Data Corrected* to Common 1957-1965 Mean	
			Tailpipe Data	FY 71 Data**
1947	15.7		14.2	
1948	19.6		18.1	
1949	15.5		14.0	
1950	16.3		14.8	
1951	16.5		15.0	
1952	17.0		15.5	
1953	15.2		13.7	
1954	14.7		13.2	
1955	13.9		12.4	
1956	13.9		12.4	
1957	12.1	6.63	10.6	8.2
1958	11.5	10.04	10.0	11.6
1959	11.8	10.80	10.3	12.4
1960	13.0	8.80	11.5	10.4
1961	13.0	5.94	11.5	7.5
1962	11.1	8.88	9.6	10.4
1963	10.6	9.44	9.1	11.0
1964	12.8	7.28	11.3	8.8
1965	11.3	11.18	9.8	12.7
1966	-	8.26	-	9.8
1967	-	7.38	-	8.9
Mean 1957-1965	11.9	8.8		

*Correction Factor (11.9-8.8)/2; subtracted from tailpipe data, added to FY 71 data.

**Excludes Denver Data and 1966/67 Los Angeles Data.

Table A-3

CO Tailpipe Measurements from Uncontrolled Cars

Model Year	Los Angeles Test Station Project[16]			Reactivity Survey[17]			1974 Car Survey[31]			Rose Bowl Survey[20]			Weighted Average
	N	Conc., %	1975 FTP, g/mi	N	Conc., %	1975 FTP, g/mi	N	Conc., %	1975 FTP, g/mi	N	1970 FTP, g/mi	1975 FTP, g/mi	`1975 FTP, g/mi
1947	4	3.68	96.7	-	-	-	-	-	-	-	-	-	96.7
1948	6	3.55	93.3	-	-	-	2	3.25	85.4	-	-	-	91.3
1949	7	4.36	114.6	1	6.62	173.0	5	4.27	112.3	-	-	-	118.2
1950	23	3.22	84.6	-	-	-	8	3.46	91.0	-	-	-	86.3
1951	25	3.78	99.4	-	-	-	13	3.89	102.3	-	-	-	100.4
1952	16	4.40	115.7	-	-	-	9	4.17	109.6	-	-	-	113.5
1953	39	3.95	103.8	2	3.49	91.5	12	2.88	75.7	-	-	-	97.0
1954	50	4.26	112.0	2	2.86	75.0	13	3.42	89.9	-	-	-	106.4
1955	89	3.44	90.4	1	2.27	59.4	26	3.57	93.9	-	-	-	90.9
1956	100	3.63	95.4	1	1.55	40.6	22	2.99	78.6	-	-	-	91.9
1957	112	3.54	93.1	6	3.75	98.1	15	2.90	76.2	-	-	-	91.4
1958	72	3.46	91.0	5	2.23	58.4	11	2.60	68.4	5	88.15	100.8	87.1
1959	109	3.06	80.4	6	2.87	75.1	17	2.81	73.9	3	33.56	38.4	78.4
1960	109	2.75	72.3	9	3.98	104.0	16	2.66	69.9	12	52.71	60.2	73.0
1961	108	3.43	90.2	16	2.92	76.4	19	2.81	73.9	14	71.38	81.6	86.1
1962	151	3.23	84.9	21	2.64	69.1	-	-	-	24	49.57	56.7	79.8
1963	13	3.19	83.1	51	2.47	64.6	-	-	-	30	75.51	86.3	74.1
1964	-	-	-	45	3.30	86.3	-	-	-	38	70.13	80.2	83.5
1965	-	-	-	46	2.89	75.6	-	-	-	35	69.97	80.0	77.5

See Notes on Table A-1

Table A-4

CO Measurements from Uncontrolled Cars

Adjusted Data

All data are 1975 FTP g/mi

Model Year	Wtd. Avg. Tailpipe Data From Table A-3	FY 71 CVS Data From Ref. 9	Data Corrected* to Common 1957-1965 Mean: Tailpipe Data	Data Corrected* to Common 1957-1965 Mean: FY 71 Data**
1947	96.7	-	97.4	-
1948	91.3	-	92.0	-
1949	118.2	-	118.5	-
1950	86.3	-	87.0	-
1951	100.4	-	101.1	-
1952	113.5	-	114.2	-
1953	97.0	-	97.7	-
1954	106.4	-	107.1	-
1955	90.9	-	91.6	-
1956	91.9	-	92.6	-
1957	91.4	81.4	92.1	80.8
1958	87.1	78.2	87.8	77.5
1959	78.4	77.3	79.1	77.6
1960	73.0	81.6	73.7	81.0
1961	86.1	79.7	86.8	79.1
1962	79.8	78.0	80.5	77.3
1963	74.1	96.5	74.8	95.8
1964	83.5	81.7	84.2	81.1
1965	77.5	87.9	78.2	87.3
1966	-	91.0		90.4
1967	-	93.6		93.0
Mean 1957-1965	81.2	82.5		

*Correction Factor (82.5-81.2)/2 = 0.65; added to tailpipe data, subtracted from FY 71 data.

**Excludes Denver Data and 1966/67 Los Angeles Data.

Table A-5

NOx Tailpipe Measurements from Uncontrolled Cars

Model Year	Los Angeles Test Station Project[16]			Reactivity Survey[17]			Rose Bowl Survey[20]			Weighted Average 1975 FTP, g/mi
	N	Conc., ppm	1975 FTP, g/mi	N	Conc., ppm	1975 FTP, g/mi	N	1970 FTP, g/mi	1970 FTP, g/mi	
1947	4	802	3.40	-	-	-	-	-	-	3.40
1948	6	831	3.53	-	-	-	-	-	-	3.53
1949	7	738	3.13	1	266	0.76	-	-	-	2.83
1950	20	1032	4.38	-	-	-	-	-	-	4.38
1951	24	985	4.18	-	-	-	-	-	-	4.18
1952	11	865	3.68	-	-	-	-	-	-	3.68
1953	31	959	4.07	2	1774	5.04	-	-	-	4.13
1954	39	742	3.15	2	2019	5.73	-	-	-	3.28
1955	77	1079	4.58	1	2270	6.45	-	-	-	4.60
1956	85	1019	4.33	1	1696	4.82	-	-	-	4.34
1957	89	1045	4.44	6	1413	4.01	-	-	-	4.41
1958	47	947	4.02	5	1558	4.42	5	4.75	5.31	4.17
1959	76	1134	4.82	6	1327	3.77	3	5.31	5.94	4.79
1960	78	1194	5.08	9	1106	3.14	12	4.87	5.44	4.95
1961	70	900	3.82	16	1665	4.73	14	3.91	4.37	4.04
1962	122	997	4.24	21	1802	5.12	22	5.64	6.31	4.63
1963	10	1033	4.39	51	1754	4.98	30	4.49	5.02	4.93
1964	-	-	-	45	1504	4.27	38	4.39	4.91	4.56
1965	-	-	-	46	1722	4.89	35	4.29	4.80	4.85

See Notes on Table A-1

Table A-6

NOx Measurements from Uncontrolled Cars

Adjusted Data

All data are 1975 FTP g/mi

Model Year	Wtd. Avg. Tailpipe Data From Table A-5	FY 71 CVS Data From Ref. 9	Data Corrected* to Common 1957-1965 Mean	
			Tailpipe Data	FY 71 Data**
1947	3.40	-	2.94	-
1948	3.53	-	3.07	-
1949	2.83	-	2.37	-
1950	4.38	-	3.92	-
1951	4.18	-	3.72	-
1952	3.68	-	3.22	-
1953	4.13	-	3.67	-
1954	3.28	-	2.82	-
1955	4.60	-	4.14	-
1956	4.34	-	3.88	-
1957	4.41	3.84	3.95	4.31
1958	4.17	3.62	3.71	4.09
1959	4.79	4.50	4.33	4.97
1960	4.95	3.94	4.49	4.41
1961	4.04	3.07	3.58	3.54
1962	4.63	3.33	4.17	3.80
1963	4.93	3.64	4.47	4.11
1964	4.56	3.67	4.10	4.14
1965	4.85	3.37	4.39	3.84
1966	-	3.57	-	4.04
1967	-	3.28	-	3.75
Mean 1957-1965	4.59	3.66		

*Correction Factor (4.59-3.66)/2 = .465; subtracted from tailpipe data, added to FY 71 data.

**Excludes Denver Data and 1966/67 Los Angeles Data.

Table A-7

NOx Test-to-Test Conversions for Uncontrolled (pre 1968) Cars

General Motors Test Program Results

Car Manufacturer	Number of Cars	1970 FTP g/mi	Average Equivalence Ratio 1972 FTP/1970 FTP
GM	15	4.06	1.20
Ford	5	3.98	0.98
Chrysler	4	4.24	0.97
AMC	1	2.96	1.08
Foreign	2	1.59	0.93
Mean		3.86	1.10

Overall average Equivalence Ratio should be weighted by car population. Reference 31 provide car population weighting factors (for the early 1960's) of:

GM	.410
Ford	.281
Chrysler	.160
Other	.088

Applying these weighting factors to the above GM results gives an overall equivalence ratio (1972 FTP/1970 FTP) of 1.082. Correcting this ratio to the 1975 FTP via the ratio of the 1975 to the 1974 standard gives: 1.082 (3.1/3.0) = 1.118 1975 FTP/1970 FTP

The following written comments on this paper were received from Marcia Williams, EPA, Office of Motor Source Air Pollution Control, Ann Arbor, Michigan and are included for information. This constitutes the only written response received to the papers presented at the workshop.

Comments on "Highway Motor Vehicle Emission Factors" paper by MVMA, presented at EPA Emission Inventory/ Factor Workshop (Sept, 1977)

The following comments are submitted after a careful review of the MVMA paper entitled "Highway Motor Vehicle Emission Factors". The MVMA paper discussed the recently released draft version of the EPA Revised Emission Factor Document. That draft is currently undergoing changes to reflect the recent 1977 Clean Air Act Amendments, some new data, and new information on California standards. The comments reflected here will pertain to the draft document used by MVMA, not the revised version of that document. MVMA has commented that the EPA document is still deficient on detailed discussions regarding the experimental data base and computational methods. This information has been carefully compiled and will be released in a separate document concurrently with the final Emission Factor Document.

Introduction

1. EPA has not concluded that CO emissions are being overestimated in the current test procedure as is implied in the MVMA paper. EPA is currently performing a study to characterize the types of driving conditions which occur in CO hot spot areas. These results will be compared with the driving patterns and test conditions (vehicle temperature, ambient conditions) which are currently reflected in the FTP. If necessary, the FTP will be modified to ensure that emission reductions achieved over the test procedure will equate to emission reductions on the road in CO hot spots. The study will also quantify the fraction of the CO problem which is due to local sources and that which is due to regional sources since typical local/regional driving conditions are not necessarily the same.

2. The MVMA paper discusses the sensitivity of ambient air quality measurements to the location of ambient monitors. The discrete nature of the monitoring system makes it impossible to properly quantify the air at every point. Likewise, since the main CO standard of concern is an 8 hour average standard, one ideally wants to average the air quality levels that a person can be expected to be exposed to under typical worst case conditions. Such conditions are likely to be those that affect policeman, airport porters, road work crews, etc. These people are breathing air at curb level and at approximately 8 feet, not at 18 feet and at the building face. Thus, the CO levels measured in NYC may be more realistic of typical worst case conditions that those measured elsewhere. The MVMA statement that "It would be extremely unfortunate if transportation control plans were established from measurements based on the shortest distance between sampling probe and tailpipe without considering public health aspects" does not appear applicable to the NYC situation as implied in the paper.

3. The MVMA paper assumes that since it is desirable to have a benchmark emission rate, it is necessary to select a model year definition for the desired benchmark. MVMA has chosen 1960 but has not specified the age or mileage of the vehicles at the time their emissions were computed. If one infers that the emission levels are measured in 1970, there is no reason for using these numbers as a benchmark. For baseline and percent reduction work, one wants to compare pre-controlled vehicles at a similar age to controlled vehicles.

EPA has determined that the exhaust emissions of pre-controlled vehicles deteriorate with mileage. The appropriate benchmark is considered to be the 50,000 mile point. Since 50,000 miles is defined as the useful life, vehicles are expected to just meet exhaust emission standards at the 50K mileage point. Thus, the 50K exhaust emission levels of pre-controlled vehicles (of all model years) can be compared with later emission standards or 50K in-use emission levels to determine the appropriate emission reductions. If desired, the evaporative and crankcase emissions, which are not assumed to deteriorate with mileage, can be added to the exhaust emissions before reductions are compiled.

Uncontrolled Exhaust Emissions

4. The recent version of the Emission Factor Document contained data on approximately 1000 precontrolled vehicles, all of which were tested over the 1975 FTP. Table I in the MVMA paper contained only a fraction of the total EPA data base. EPA considers the use of the MVMA concentration data base to be highly questionable. The ability to accurately convert concentration data to mass data is difficult if not impossible. (The MVMA Appendix to the paper supports this fact.) Both EPA and CARB have stated that since such conversions are extremely vehicle dependent, they should not be performed on in-use emission factor data bases.

The incorrect use of a single conversion factor over many model years and vehicle mixes could account for the downward trend in emissions shown in Figures 1, 2, and 3. The other factor which could account for an artificial downward trend is the testing of different model year vehicles at different mileage/age points. EPA FTP data do not support a downward emission trend from 1957 to 1967 although within each model year, a trend with mileage/age is apparent.

Uncontrolled Evaporative Emissions

5. MVMA suggests that the MIT method be used to convert from grams/test to grams/mile. The EPA procedure is based on the most recent national average trip statistics while the origin of the MIT statistics are unclear (the 7.5 miles/trip figure is based on over 10 year old data from Los Angeles; the basis for the 27 mile/day figure is not known).

The inclusion of running losses is not possible at this time due to the absence of a defendable procedure over which to measure the losses. In order for vehicle operation to cause evaporative emissions in excess of those produced during the diurnal phase, the vehicle operation must result in a temperature rise of the fuel tank which is greater than that which occurs during the diurnal. At this time, the extent of these losses in real world operation have not been adequately quantified in order to include them in the evaporative emission factor.

Controlled Exhaust Emissions

6. Post-1974 vehicles - The EPA regression equations for 1975 model year vehicles were performed by dividing all vehicles into two distinct groups: within specification vehicles and out of specification vehicles. Regressions were performed on each group and the results were weighted to get a final deterioration equation. It is this difference in analysis methods that accounts for the difference in the MVMA and EPA linear regression estimates. The correlation coefficients for the EPA data are higher than the MVMA values. Moreover, data from the recently completed FY75 Emission Factor Program support the earlier regression equations and linearity assumption. The logarithmic model used by MVMA has been discredited for pre-1975 models as more data have been collected; CARB no longer uses the model.

   While an increase of CO normally is associated with a decrease in NOx for a given vehicle, the correlation is not excessively strong for newer model vehicles. More importantly, as vehicles accumulate age, the types of maladjustments that cause high CO (and lower NOx) can be totally offset by concurrent maladjustments to the EGR system.

   EPA estimates of future model year emission levels are based on a technology evaluation model. The model projects the percentage of vehicles that are properly tuned, maladjusted, and have emission control systems inoperable as a function of vehicle age. Using manufacturer supplied data on the emission behavior of future control systems under various malfunction conditions, the composite emission rates as a function of mileage can be computed. These regressions assume that some type of EPA regulation regarding limited vehicle parametric adjustability will be in effect by the 1980 model year.

7. 1968-1974 Cars - The straight linear regression approach used by MVMA is not an optimal regression approach due to the large scatter in the data. The EPA has applied a regression analysis using mean emissions and mean mileage inputs for each model year vehicle group in each test program. The result of this type of analysis is to

predict mean emissions of groups of vehicles (not individual vehicles) as a function of mileage/age. The correlation coefficients for a linear model are excellent (greater than .8) for a range of data that goes from low mileage to approximately 80,000 miles. The regression equations were used to predict the results in the most recent test program and predictions were correct within 10 percent.

Controlled Evaporative Emissions

8. The EPA emission factor data are based on three separate EPA test programs. All three programs gave similar results. The possibility of gas tank cap leaks was carefully checked and EPA is convinced that significant leakage did not occur.

   Regarding the test data presented in Table 4 (referred to in the text as Table 5), the vehicles in the Exxon Study were fitted with new fuel tanks prior to the test so that the vehicles would not be typical of in-use vehicles.

Truck Exhaust Emission Factors

9. Although the heavy-duty trucks are not subject to a chassis dynamometer (grams/mile) certification test, EPA has collected emission data from these vehicles over chassis dynamometer transient tests and over a real road route in Texas.

10. Figure 11 is not clearly labeled but there are believed to be two discrepancies in the MVMA comparisons; pre-controlled vehicles had much higher mileages at time of test than 1972-73 models (emission deterioration was not adjusted for); 1972-73 trucks were tested in a tuned condition and pre-controlled trucks were tested in an as-received condition.

CONDENSED DISCUSSION

COMMENT: I have one comment on your procedure you recommend for evaporative loss emission factors. The intent that we (EPA) had in putting that equation in there is that area specific data be used. In other words your origin-destination data for a number of trips per day per vehicle and average trip lengths - you put that into that equation. As I see what you are doing, you are putting in a different set of default values, and it was not our intent. At least in Supplement 5, that equation to recommend default values was only to make it so that people could put in individual urban data.

FAGLEY: The point we were trying to make in the paper is that the numbers for evaporative emissions come out of the test cycle. That has a mileage associated with it. You know that might not be appropriate to particular urban areas being addressed, but that was the basis the actual measure of emissions. So they made the hot soak emissions associate with 7.5 miles. Not some other value like ten or something elese.

COMMENT: Again, I think that you could use any default value. You chose one a little bit lower than we did. The difference is not very significant. I do think we should look into running losses. But that is just a personal observation.

FTP Emission Factor Development:
Correction for non-FTP Conditions

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

Janet Becker
Mathematical Statistician

Marcia Williams
Chief

U.S. Environmental Protection Agency
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Characterization and Applications Branch

I. Introduction

The problem of estimating exhaust emission levels from in-use light duty vehicles has been of interest for many years, dating back to the early 1950's in California. However, this problem did not receive a federal mandate for action until the passage of the Clean Air Act of 1963 and the Clean Air Act Amendments of 1970, which called for a 90% reduction in HC and CO from allowable 1970 levels, and for a 90% reduction in NOx from average NOx emission levels actually measured from light duty vehicles manufactured during model year 1971. These reductions were originally to be achieved by model year 1976, but a series of one year extensions and the 1977 Clean Air Act has revised final implementation dates until at least 1981.

The federal government has implemented programs designed to ensure that properly maintained and used vehicles meet emission standards in the field. These programs include certification, assembly line testing, and recall. However, the states and/or air quality control regions (AQCRs) were given the basic responsibility for preparing plans under which the progressively more stringent national ambient air quality standards could be achieved. Of necessity, a part of any such plan includes a statement regarding the impact of motor vehicle emissions on air quality, and, if appropriate, methods for controlling the exhaust emissions from in-use vehicles.

To help states and AQCRs in the development of such plans and to help estimate the deterioration of emissions in a real world environment, the EPA instituted the Emission Factor Program in FY 1971.

This program is designed to estimate areawide urban emission levels for in-use vehicles on a nationwide basis. Although testing of other than light duty vehicles has occurred in recent years, the emphasis of the program has been on estimating passenger car emission levels. Testing of vehicles occurs in cities representing various climatic and geographic conditions. Light duty vehicles are currently tested according to the 1975 Federal Test Procedure (FTP) as stipulated in the Federal Register[1]. Illustration 1 summarizes the conditions and assumptions which occur with the FTP. The FTP driving cycle has been determined to be a reasonably representative urban stop-and-go commute on the basis of data collected in Los Angeles in the 1960's. The ambient conditions are not inherent in the driving cycle, but were established as part of the FTP to ensure comparability of FTP test results. The hot/cold weighting factor used in the FTP is not inherent in the driving cycle, but was determined to be representative of the percent of hot start vs. cold start miles on the basis of data collected in Los Angeles.

---

[1] Federal Register, Vol. 137, No. 211, Nov. 15, 1972.

Thus, the estimates of exhaust emission levels derived from the annual Emission Factor Programs are representative of emission levels in areawide urban scenarios which conform to the assumptions and conditions specified in Illustration 1. These estimates are updated annually, and are published in AP-42, Compilation of Air Pollution Emission Factors. For scenarios which do not conform to the FTP conditions and assumptions, AP-42 estimates are more or less inappropriate, depending on the extent of the nonconformity. Therefore, in recent updates to AP-42, starting with Supplement 5, so-called "correction factors" have been provided and recommended for use in incorporating scenario-specific considerations into emission estimates. The next supplement on mobile source emission factors was originally scheduled for promulgation as AP-42, Supplement 8, and will contain light duty vehicle correction factors for ambient temperature, average speed, % hot start/% cold start operation, humidity, air conditioning, and extra vehicle loading. This supplement number is no longer firm; however, the Supplement 8 designation will be used throughout this document. This paper will focus on the methodology used to correct FTP exhaust emission estimates for ambient temperature, average speed, and % hot start/% cold start operation (hot/cold).

II. Data Bases

In order to correct for non-FTP conditions and assumptions, it is necessary to have data taken under non-FTP conditions to compare with AP-42 numbers. There were two data bases available to EPA, representing FTP testing which occurred outside the FTP ambient temperature range of 68 to 86°F. One set of data was provided by the study Ambient Temperature and Vehicle Emissions (EPA 460/3-74-028, October 1974), in which FTP emission tests were performed on 26 1967-1974, and 1975 prototype model year non-California light duty cars at ambient temperatures of 20° to 110°F. Most cars underwent four tests at ambient temperatures of 20°, 50°, 75°, and 100°F respectively. The other set of data was provided by the Environmental Protection Service, Ottawa, Ontario, and represents FTP emission tests on 12 1975 model year light duty vehicles, 7 of which were designed to meet which federal emission standards, and 5 of which were designed to meet the more stringent California emission standards. Multiple tests were performed on each vehicle at ambients of 0° to 80°F. For both data sets, the NOx emissions were normalized to 75 grains of water/lb. of dry air, as stipulated by the FTP[2]. Also, all cars were in a tuned-up condition immediately prior to testing. A description of each set of vehicles is provided in Illustrations 2 and 3 respectively. Illustration 4 summarizes some of the characteristics of these two fleets.

III. Methodology of Correction Factor Development

The general approach to developing correction factors in both Supplement 5 and Supplement 8 has been to calculate multiplicative factors which are applied to the AP-42 estimates of HC, CO, and NOx. The final forms of the Supplement 5 and Supplement 8 correction factors are given in Illustration 5, and are viewed as part of the basic emission factor calculation. In Supplement 5 three separate factors were used to correct for temperature, average speed, and hot/cold operation, respectively. Due to lack of data, the possibility of interaction among these three factors was by and large disregarded. In the process of developing Supplement 8 correction factors it was decided on the basis of the newly available Canadian data that interaction between ambient temperature and hot/cold operation was significant enough to warrant the use of a single, more complex correction factor which would incorporate the interdependence of the temperature and hot/cold variants. Future correction factor work will probably be oriented towards the development of one correction factor which incorporates the interdependency among all factors affecting exhaust emission levels. Although joint data on average speed and hot/cold operation were not available, it was felt that the modeling of an interaction between these factors was appropriate. Certain assumptions, which will be discussed later, had to be made in order to incorporate this interdependency. One correction factor, the R' correction factor, results in Supplement 8 and consists of temperature, hot/cold operation, and average speed components.

---

[2] Federal Register, Vol. 28, No. 151, August 7, 1973.

The approach to calculating the R' factor was to first develop the temperature-hot/cold portion by finding an expression for $CF_{t,w,x}$ which solves the following equation:

Equation 1: $FTP_{t,w,x} = (CF_{t,w,x})\ (FTP_{75°,\ .2058,\ .2728})$,

where t = ambient temperature (°F),

w = fraction of total miles driven which are driven in cold start operation (representative of emissions which occur on and shortly after start-up following a long engine-off period),

x = fraction of total miles driven which are driven in hot start condition (representative of emissions which occur on and shortly after start-up following a short engine-off period),

$FTP_{t,w,x}$ = emissions (gm/mi) as measured over the FTP driving cycle at t°F, with a % hot start/% cold start operation ratio of x/w.

The situation where t is 75°F, w is .2058, and x is .2728 defines the FTP conditions and assumptions for ambient temperature and hot/cold operation. (Although the FTP requirement is only that vehicles be tested in an ambient temperature range of 68-86°F, 75° was taken as representative of the temperature range used for FTP testing). As discussed previously, the FTP conditions are reflected in AP-42 emission estimates. The above Equation 1 is equivalent to Equation 2:

Equation 2: $$CF_{t,w,x} = \frac{FTP_{t,w,x}}{FTP\ 75°,\ .2058,\ .2728}$$

The ambient temperature - hot/cold portion of the R' correction factor is based on Equation 2. Thus, in conjunction with this formulation of correction factors an expression for $FTP_{t,w,x}$ was fundamental.

An equation for $FTP_{t,w,x}$ can be formulated as follows:

Equation 3: $FTP_{t,w,x} = w(\text{Bag } 1)_t + (1-w-x)(\text{Bag } 2)_t + x(\text{Bag } 3)_t$,

where $(\text{Bag } i)_t$ = emissions (gm/mi) in Bag i, i=1,2,3, at temperature t.

The next step was to determine Bag 1,2, and 3 emissions as an appropriate function of ambient temperature.

The data provided by the Environmental Protection Service on 1975 model year cars included extensive replicate testing on each vehicle at ambient temperatures of approximately 0 to 80°F. It was felt that these data would provide the best estimate of the appropriate functional form for each bag's gm/mi as a function of temperature, since each vehicle's data represented a unit for analysis in and of itself. Data on vehicles which were designed to meet California emission standards were analyzed separately from data on vehicles which were designed to meet the federal emission standards.

For each pollutant (HC, CO, and NOx), bag 1[3], bag 2, and bag 3 emissions (gm/mi) were analyzed to determine the effect, if any, of ambient temperature on emission levels. Based on an examination of scatter plots of emissions vs. temperature and an examination of residuals from the linear and loglinear regression models, the loglinear model was selected. The regression model was as follows:

Equation 4: $\ln(y) = a_0 + a_1 t$,

where ln = natural logarithmic function,

y = emissions (gm/mi),

t = ambient temperature (°F).

Due to the confounding effects of car-to-car variability which arise when analyzing emission data on several different vehicles, it was decided that covariance analysis could be useful in the determination of an appropriate slope for the regression line. Large experimental errors due, in this case, to car-to-car variability would be encountered in a regression analysis which does not stratify on vehicle, and would possibly result in an inaccurate regression slope. By stratifying on vehicle for the analysis of covariance, smaller experimental errors result. Thus, the relationship between emissions and temperature becomes clearer.

---

[3] Bag 1 represents emissions which occur on and shortly after start-up, following a long engine-off period (cold start), bag 2 represents emissions which occur when a vehicle's engine and/or emission controls are in a warmed-up condition (stabilized), and bag 3 represents emissions which occur on and shortly after start-up, following a short engine-off period (hot start).

Only bag 1 HC and bag 1 CO emission levels appeared to change significantly with temperature. The expressions for these bag's emissions in terms of temperature, derived from the best-estimate slope determined by the analysis of covariance and the average of the individual vehicle regression intercepts, are presented in Illustration 6. It is emphasized that these prediction equations reflect emission-temperature relationships for 1975 model year vehicles in a tuned-up condition. As a check on the robustness of these equations, a visual comparison of the observed average bag 1 HC and bag 1 CO emissions for the 4 1975 model year prototype cars tested in the EPA study Ambient Temperature and Vehicle Emissions with the predicted values was made. The emissions predicted from the prediction equations indicated reasonable predictability of bag 1 HC and bag 1 CO emissions for these vehicles. The observed and predicted emissions are presented in Illustration 7.

Also on the basis of these visual comparisons, it was decided that extrapolation of the prediction equations to 110°F was reasonable. The expressions presented in Illustration 6 are therefore considered appropriate for temperatures in the range 0 to 110°F. Although the expressions are based on data for 1975 model year cars, they are assumed applicable to 1975-79 cars, since technology over these years has not changed and probably will not change substantially.

The only source of ambient temperature-emissions data on pre-1975 model years cars available to EPA was the study Ambient Temperature and Vehicle Emissions. Since at most four FTP tests were performed on a single vehicle, the reliability of a functional form derived on the basis of these data alone was considered poor. The general functional form for the pre-1975 model year cars' temperature-emissions relationships were therefore taken to be loglinear, this form having been determined acceptable for 1975 model year cars. Using this regression model, an analysis of covariance was performed on all pre-1975 model year cars' data to determine expressions for bag emissions (gm/mi) in terms of ambient temperature. As was the case for the 1975 model year data, only bag 1 HC and bag 1 CO emissions appeared to be significantly affected by ambient temperature for pre-1975 cars. The expressions for bag 1 HC and bag 1 CO emissions for pre-1975 model year cars are displayed in Illustration 8. (A separate analysis of pre-controlled cars' data yielded relationships similar to those for 1968-74 model year cars, so all pre-1975 data were combined).

Since states and Air Quality Control Regions are interested in estimating the emission levels of in-use, as opposed to tuned-up vehicles, the expressions for bag 1 HC and bag 1 CO emissions which are given in Illustrations 6 and 8 were modified by adding a constant equal to the difference between low mileage (10,000 miles) AP-42 bag 1 FTP emission levels, and bag 1 emission levels at 75° as predicted by the expressions for tuned-up vehicles. At this point in the development, the temperature - hot/cold correction factors took the following form:

$$CF_{preliminary} =$$

$$\frac{w\ [\exp\ (a_0 + a_1\ t) + c] + (1-w-x)\ (d) + x\ (e)}{.2085\ [\exp\ (a_0 + 75\ a_1) + c] + .5213\ d + .2728\ e,}$$

c = difference between AP-42 low mileage bag 1 emissions (gm/mi) and bag 1 emissions at 75° as predicted by the expressions for tuned-up vehicles,

d = AP-42 low mileage bag 2 emissions (gm/mi),

e = AP-42 low mileage bag 3 emissions (gm/mi),

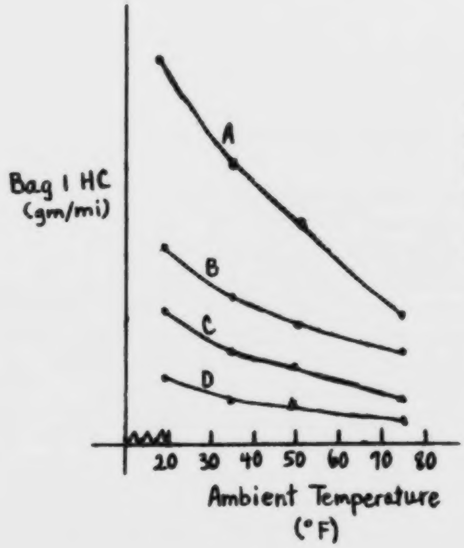
w = fraction of total miles driven which are driven in cold start condition,

x = fraction of total miles driven which are driven in hot start condition.

For the above equation, FY72 and FY74 emission factor data on pre-1975 and 1975 model year cars, respectively, were used to calculate the percentages of the FTP which were in bags 1, 2, and 3, respectively, for precontrolled cars, for 1968-74 model year cars, and for 1975 model year cars. These percentages were applied to the AP-42 low mileage FTP levels for each model year group to obtain the values for c, d, and e. The denominator in the above expression for CF preliminary is a low mileage normalizing value, equal to the low mileage FTP level under the FTP assumptions.

A review of these preliminary temperature - hot/cold correction factors resulted in a decision that a mileage or age consideration should be incorporated. This decision was based on the fact that these factors were extremely sensitive to the FTP levels at 75° which were used as normalizing factors. For example, the preliminary correction factors described above, which were based on low mileage normalizing factors, were often substantially different from those which were based on 100,000 mile normalizing factors. The underlying assumption in applying a set of correction factors which are normalized to a fixed mileage is that the predicted steepness of the effect of low temperature on emissions depends on mileage accumulation, as illustrated below. However, available data from the EPA study suggest that the assumption of such a dependency is unwarranted. Thus, the use of correction factors which are normalized to a fixed mileage is considered inappropriate.

Prediction of HC Bag 1 Emissions (gm/mi)
Fixed-mileage Normalized Temperature -
Hot/Cold Correction Factors
1975 Model Year Federal Light Duty Vehicles



All Cold Start Driving CFs*

	Normalized to 10,000 miles	Normalized to 100,000 miles
20°	5.64	2.67
35°	4.10	2.14
50°	3.03	1.76
75°	1.89	1.36

* Curves A and C are based on the application of the 10,000 mile normalized CFs to the 100,000 mile AP-42 FTP (3.94) and to the 10,000 AP-42 HC FTP (1.38), respectively. Curves B and D are based on the application of the 100,000 mile-normalized CFs to the FTP levels 3.94 and 1.38, respectively.

A consideration of vehicle age (mileage) was incorporated into the expression for the temperature - hot/cold correction factors in the following way:

$$CF = \frac{w[\exp(a_0 + a_1 t) + c + A\,df_1] + (1-w-x)(d + A\,df_2) + x(e + A\,df_3)}{.2058[\exp(a_0 + 75a_1) + c + A\,df_1] + .5213(d + A\,df_2) + .2728(e + A\,df_3)},$$

where

df_j = deterioration factor (gm/mi/year) in bag j, j = 1,2,3,

A = (vehicle age-1), in years; A = 0 to 9. (One year is assumed to be equivalent to 10,000 miles).

The above expression for CF is equivalent to the following:

$$CF = \frac{w[\exp(a_0 + a_1 t) + c + A\,df_1] + (1-w-x)(d + A\,df_2) + x(e + A\,df_3)}{v + Ar},$$

where

v = low mileage AP-42 FTP emission factor at 75°,

r = AP-42 FTP deterioration factor (gm/mi/yr) at 75°.

With regard to the above expression, for pre-1975s the assumption was made that, for a given pollutant, percent deterioration per year occurring in bag i (based on low mileage AP-42 emission factors, by bag), which is fairly constant for all bags at 75°*, is constant for all temperatures. (The percent deterioration in each bag is assumed to equal the overall percent deterioration, r/v). For 1975-77 model year cars, the percent deterioration which occurs in bags 2 and 3 has been shown to differ from that in bag 1 for all pollutants.* For HC and CO, percent deterioration is greater in bags 2 and 3 than in bag 1. For NOx, deterioration is less in bags 2 and 3 than in bag 1. The bag specific gm/mi/yr deterioration factors were obtained by multiplying the percent deterioration by the AP-42 low mileage bag 1, bag 2, and bag 3 emission levels. The basic input values for the terms in the above expression for CF are given in Illustration 9.

---

*July 20, 1976 internal EPA memo.

Incorporation of Speed Correction Factors: So far the discussion of ambient temperature, average speed, and hot/cold correction factors has centered around considerations of temperature and hot/cold operation. Separate consideration of the speed portion was necessary due to the lack of data covering all three factors at once. Despite the lack of data, bag-specific speed correction factors were incorporated into the correction factors for temperature and hot/cold weighting as opposed to being given as separate factors. Although the available bag-specific data on speed effects were insufficient for analysis purposes, engineering judgment supports the assumption of a hot/cold-speed interdependency.

Until further data on speed-temperature interdependencies become available, speed and temperature effects on emissions will be assumed to be independent. This assumption will be checked as data become available. The result of incorporating speed correction factors into the temperature - hot/cold correction factors given above is more accurate predicted emission levels, at the expense of quite complex correction factor calculations, if carried out by hand. Due to this complexity, EPA is currently in the process of computerizing the calculation of these factors. The derivation of the speed correction factors and the final temperature, ambient temperature, hot/cold correction factors is discussed below.

Derivation of Speed Correction Factors: Speed correction factors for warmed-up vehicle operation were developed using a four stage process. First, large quantities of second-by-second speed-time data were collected, divided into acceleration, deceleration, and steady state modes, and transcribed into transition probability matrices. A transition probability matrix gives the probability that a vehicle moves to speed x given that it is currently at speed y. The data used to develop the transition probability matrix were collected in the 1970 Vehicle Operations Survey and the 1974 GM Chase Car Survey, and covered 1957-1975 model year vehicles.

The second stage of the procedure generated second-by-second speed-time cycles at average speeds between 5 and 60 mph. Monte Carlo simulation techniques were applied to generate cycles based on the transition probability matrix, and cycles were screened so as to have the appropriate amount of idle time, acceleration time, deceleration time, cruise time, and average speed, as determined from the observed average driving cycle. Multiple cycles were generated for each average speed point. All cycles were transient; no steady state only cycles were generated.

Each of the transient speed-time cycles was fed into the EPA modal emission model (EPA Report No. 460-3-74-065). The modal emission model is a mathematical regression model which predicts warmed-up vehicle emissions in gm/mi over arbitrary transient driving sequences from speed-time data. The model is based on modal input data from approximately 2000 1957-1975 model year vehicles. For each model year vehicle, emission estimates were obtained for each of the generated speed-time sequences.

Plots were made of predicted emissions vs. average speed and regressions were performed. In all cases, the r^2 value was above .95. The regressions were then normalized to the average speed of 19.6; that is, an average speed of 19.6 will give a correction factor of 1.0. Illustration 10 lists the model year/city groupings for which speed correction factors for warmed-up vehicle operation were formulated, and Illustration 11 lists the formulas for the speed correction factors (normalized to 19.6 mph) for stabilized and hot start driving conditions. Illustration 12 provides the stabilized and hot start speed correction factors in 5 mph increments. All HC and CO regressions are exponential fifth order polynomials. All NOx regressions are fourth order polynomials. This work was performed under an EPA contract to Olson Laboratories. More detailed information on the development of the speed correction factors can be found in the contract final report which should be available by late 1977.

These speed correction factors for stabilized and hot start operation were used to derive bag-specific correction factors. The need for bag-specific correction factors is based on two considerations. First, the fact that the cold and hot bags of the FTP have a different average speed from the stabilized bag indicates a need for bag-specific speed factors. That is, if the percentage operation in each of the bags is altered, the average speed will also be altered. The second reason is more complex. The speed correction factors discussed up until now were developed to predict changes in warmed-up vehicle emissions. It is not reasonable, from an engineering standpoint, to expect these same emission changes to occur during cold operation because of the operation of the choke: Pre-controlled vehicles were calibrated with rich air-fuel mixtures and as a result, the difference in cold emissions and hot emissions at a given average speed is not as great as for later model year vehicles in which the air-fuel mixtures are leaner. During cold operation of controlled vehicles, the operation of the choke can be expected to result in a situation where emissions are relatively less sensitive to changes in average speed than to changes due to choke operation. Lacking conclusive data, the emission dependency on speed during cold operation is assumed to be similar for all model year vehicles and to be equal to the dependency of pre-controlled vehicles during warmed-up operation.

The calculations of the bag-specific speed correction factors for a given pollutant were made according to the following equations:

$$\text{Bag 1 speed correction factor} = v_{2,s_1}/v_{2,26}$$

$$\text{Bag 2 speed correction factor} = v_{g,s_2}/v_{g,16}$$

$$\text{Bag 3 speed correction factor} = v_{g,s_3}/v_{g,26},$$

where s_i = average speed in bag i, i=1,2,3

$v_{(g,s_i)}$ = group-specific speed correction factor for warmed-up operation normalized to 19.6 mph (g=2 designates pre-controlled low altitute vehicles).

Due to lack of data, a consideration of modal effects in a cycle of interest, such as the cycle's percent time or percent miles spent in acceleration, deceleration, and idle, or the sequence of modes in the cycle has not been included in the development of the speed correction factors. Although EPA has not investigated this question thoroughly, it appears that for HC and CO as measured over various transient cycles, the average speed difference accounts for the majority of the effect on emission. NOx emission seems to be influenced a little more by the cycle than is HC or CO emission, although speed still has the major impact. It is expected that cycles with higher percentages or rates of acceleration will have higher NOx emissions for the same average speed.

The bag-specific speed correction factors were incorporated into the temperature-hot/cold factors, resulting in the general formulas presented in Illustrations 13 to 15.

Applicability of Correction Factors: The general correction factors are applicable to ambient temperatures of 0-110°F, speeds of 5 to 60 mph, and all combinations of hot/cold driving. Also, the factors should only be applied to transient driving situations. To predict the emissions of a steady state driving sequence such as constant 20 mph operation, the modal model should be applied to the specific speed of interest and/or EPA surveillance reports should be referenced. The difference between emissions as measured over steady state vs. transient cycles is considerable at low average speeds (greater than 20 percent) and becomes negligible at speeds of around 45 mph.

Illustration 1

1975 Federal Test Procedure Conditions for Light Duty Vehicles

1. Ambient temperature = 68° - 86°F (An average temperature of 75°F is assumed to be representative of all tabled emission factor values).

2. Ambient humidity = 75 grains

3. Average speed for entire FTP driving cycle = 19.6 mph, 18% idle operation.

    a. Average speed for bags 1 and 3 (cold and hot start bags) = 26 mph

    b. Average speed for bag 2 (stabilized bag) = 16 mph

4. Average % cold start VMT operation = 20.58%

5. Average % hot start VMT operation = 27.28%

6. Average % stablilized VMT operation = 52.13%

7. Air-conditioning does not pull large power load

8. Car contains driver and fuel only, no passengers, luggage, etc.

9. Car is not pulling a trailer

Illustration 2

Environmental Protection Agency Study Fleet[1]

Model Year	Make & Model	Engine Size	Transmission[2]	Emission Control[3]
1967	Ford Galaxie	289	A3	PCV
1967	Chevrolet Impala	283	A2	PCV
1967	Plymouth Fury	318	A3	PCV
1969	Chevrolet Malibu	307	A2	EM, PCV
1969	Ford Galaxie	302	A3	EM, PCV
1969	AMC Ambassador	290	A3	EM, PCV
1969	Mercury Montery	390	A3	EM, PCV
1970	Oldsmobile Cutlass	350	A3	EM, PCV
1970	Chrysler Newport	383	A3	EM, PCV
1971	Ford Galaxie	351	A3	EEC, EM, PCV
1971	Chevrolet Impala	350	A3	EEC, EM, PCV
1971	Dodge Coronet	318	A3	EEC, EM, PCV
1971	Buick Electra	455	A3	EEC, EM, PCV
1971	Chevrolet Impala	400	A3	EEC, EM, PCV
1972	Ford Torino-C	351	A3	EEC, EM, PCV
1973	Volvo 142	121	M4	EGR, EFI
1973	Chevrolet Laguna	350	A3	EGR
1973	Ford LTD	351	A3	EGR
1974	Ford Torino-C	351	A3	EGR, MAI
1974	Plymouth Fury III	360	A3	EGR
1974	Chevrolet Chevelle	350	A3	EGR, MAI
1974	Ford Torino	351-W	A3	EGR
Prototype 1975	Ford Pinto	140	A3	EGR, MAI, Ox. Cat.
Prototype 1975	Plymouth Satellite	318	A3	EGR, MAI, Ox. Cat.
Prototype 1975	Ford LTD	400	A3	EGR, MAI, Ox. Cat.
Prototype 1975	Chevrolet Belair	350	A3	EGR, MAI, Ox. Cat.

[1] Ambient Temperature and Vehicle Emissions, EPA Report 460/3-74-028, October 1974.

[2] Transmission Code
A2 - automatic 2-speed
A3 - automatic 3-speed
M4 - manual 4-speed

[3] Emission Control Code
PCV - positive crankcase ventillation
EM - engine modifications
EEC - evaporative emission control
EGR - exhaust gas recirculation
MAI - manifold air injection
Ox. Cat. - oxidizing catalytic converter

Illustration 3

Environmental Protection Service Fleet: 1975-1976

1975 Model Year Cars

Make & Model	Engine Size	Transmission[1]	Emission Control[2]
Chevrolet Impala	350	A3	EGR, Ox. Cat., MAI
Chevrolet Biscayne (Calif.)	350	A3	EGR
Honda CIVIC (Calif.)	90.8	M4	CVCC[3]
Honda CIVIC (Calif.)	90.8	M4	CVCC[3]
Chevrolet Monza (Calif.)	140	A3	EGR, Ox. Cat., MAI
Dodge Dart (Calif.)	318	A3	EGR, Ox. Cat., MAI
Ford Maverick	250	A3	EGR, MAI
Ford Custom 500	351	A3	EGR, MAI
Dodge Dart	225	A3	EGR
Chevrolet Nova	250	A3	EGR, Ox. Cat.
AMC Hornet	258	A3	EGR
Dodge S/W Monaco	440	A3	EGR

[1] Transmission Code
A3 - automatic 3-speed
M4 - manual 4-speed

[2] Emission Control Code
EGR - exhaust gas recirculation
MAI - manifold air injection
Ox. Cat. - oxidizing catalytic converter

[3] Compound Vortex Controlled Combustion - CVCC is a stratified charge system engine design which is used in place of auxillary emission control devices.

Illustration 4

Ambient Temperature Data Bases

1. Ambient Temperature and Vehicle Emissions (EPA 460/3-74-028, October 1974)
2. Environmental Protection Service, Ottawa, Ontario: 1975-76 Cold Weather Fleet.

Data Base Characteristics

Source	No. Vehicles	No. Tests per Vehicle (Range)	Total Tests	Model Years Represented	Ambient Temperature Range
1.	26	3-4	96	1967-1975	20 to 110°F
2.	12	18-59	479	1975 Federal and California	0 to 80°F

Illustration 5

Basic Emission Factor Equation - Light Duty Vehicles

Supplement 5

$$E_{npstwx} = \sum_{i=n-12}^{n} c_{ipn}\, M_{in}\, V_{ips}\, Z_{ipt}\, R_{iptwx}$$

Supplement 8

$$E_{npstwx} = \sum_{i=n-12}^{n} c'_{ipn}\, M_{in}\, R'_{ipstwx}\, A_{ip}\, L_{ip}\, U_{ipw}\, H_{ip}$$

i = model year

n = calendar year

s = speed

t = ambient temperature

w = fraction cold operation

x = fraction hot start operation

p = pollutant

c, c' = emission factor in AP-42 tables

M = fraction of total mileage

V = average speed cf

Z = temperature cf

R = hot/cold cf

R' = temperature, average speed, and hot/cold cf

A = air-conditioning cf

L = vehicle load cf

U = trailer towing cf

H = humidity cf

Illustration 6

Prediction of Bag 1 HC and Bag 1 CO Emissions from Ambient Temperature 1975 Model Year Vehicles in a Tuned-up Condition

1975 Model Year Federal Cars:
Bag 1 HC: $y = \exp\ (2.4339 - .023591t)$
Bag 1 CO: $y = \exp\ (5.5460 - .028945t)$

1975 Model Year California Cars:
Bag 1 HC: $y = \exp\ (1.9934 - .022269t)$
Bag 1 CO: $y = \exp\ (4.2391 - .017522t)$,

where y = emissions (gm/mi), exp = natural exponential function, t = ambient temperature (°F). The equations are based on data for 12 1975 model year vehicles tested at ambient temperatures of 0° to 80°F. A total of 479 tests were performed.

Illustration 7

Observed* vs. Predicted** Emissions (gm/mi) for Four 1975 Prototype Vehicles

Bag 1 HC

	Ambient Temperature (°F)			
	20°	50°	75°	110°
Observed Level	5.2	2.6	1.3	1.0
E.P.S. Federal Predicted Level	7.1	3.5	1.9	.85***
E.P.S. California Predicted Level	4.7	2.4	1.4	.63***

Bag 1 CO

	Ambient Temperature (°F)			
	20°	50°	75°	110°
Observed Level	126.3	67.5	17.0	10.1
E.P.S. Federal Predicted Level	143.6	60.3	29.2	10.6***
E.P.S. California Predicted Level	48.9	28.9	18.6	10.1***

* Observed levels were taken from EPA study 460/3-74-028, Ambient Temperature and Vehicle Emissions.

** Predictions were based on the results of covariance analyses performed on the Environmental Protection Service data on federal and California cars, respectively.

*** Extrapolated values.

Illustration 8

Prediction of Bag 1 HC and Bag 1 CO Emissions from Ambient Temperature Pre-1975 Model Year Vehicles in a Tuned-up Condition

$$\text{Bag 1 HC: } y = \exp(2.9310 - .014779t)$$

$$\text{Bag 1 CO: } y = \exp(5.6548 - .015965t),$$

where y = emissions (gm/mi), exp = natural exponential function, t = ambient temperature (°F). Equations are based on data for 22 1967-74 model year cars tested at ambient temperatures of 20° to 110°F from EPA study 460/3-74-028, October 1974. A total of 83 tests were performed.

Illustration 9

Numerical Inputs to Correction Factor Expressions

		a_1	a_o	c	e	d	v	r	rc	rh
Pre-1968	HC	-0.014779	2.9310	.673	4.746	5.685	5.67	0.47	0.47	0.47
	CO	-0.015965	5.6548	-14.74	42.84	57.57	56.43	7.59	7.59	7.59
	NOx	0.	0.	2.876	4.25	2.768	3.40	0.	0.	0.
1968-74	HC	-0.014779	2.9310	-2.41	2.43	2.61	2.8	0.64	0.64	0.64
	CO	-0.015965	5.6548	-33.89	25.26	35.9	36.4	6.79	6.79	6.79
	NOx	0.	0.	4.44	5.92	3.77	4.7	0.	0.	0.
1975 Federal	HC	-0.023591	2.4339	0.623	1.11	1.053	1.38	0.28	.162	.3532
	CO	-0.028945	5.5460	11.29	15.855	21.167	23.7	3.14	2.48	3.50
	NOx	0.	0.	2.26	2.989	1.887	2.47	0.18	.2540	.1524
1975 Calif	HC	-0.022269	1.9934	-.032	.497	.243	0.54	0.28	.178	.388
	CO	-0.017522	4.2391	-0.20	4.12	3.96	6.98	3.14	2.645	3.729
	NOx	0.	0.	2.05	2.88	2.009	2.46	0.18	.2563	.1538

The values for df_1, df_2, and df_3 were calculated from the following formulas:

$$df_1 = (rc/v)*(EXP(75.*a_1+a_o)+c)$$

$$df_2 = (rh/v)*d$$

$$df_3 = (rh/v)*e.$$

Illustration 10

Group Definitions for Speed Correction Factors

Group Number	Group Definition
Group 1	Denver pre-controlled
Group 2	All low altitude cities pre-controlled
Group 3	1966-1967 California
Group 4	1968 low altitude cities
Group 5	1969 low altitude cities
Group 6	1970 low altitude cities
Group 7	1971 low altitude cities
Group 8	1968 Denver
Group 9	1969 Denver
Group 10	1970 Denver
Group 11	1971 Denver
Group 12	1972 Denver
Group 13	1972 Los Angeles
Group 14	1972 low altitude cities
Group 15	1973-1974 Denver
Group 16	1973-1974 Los Angeles
Group 17	1973-1974 low altitude cities
Group 18	1975 low altitude cities

Illustration 11

Speed Correction Factor Formulas

Normalized Equations

$$\ln HC = A_0 + A_1 s + A_2 s^2 + A_3 s^3 + A_4 s^4 + A_5 s^5$$

$$\ln CO = A_0 + A_1 s + A_2 s^2 + A_3 s^3 + A_4 s^4 + A_5 s^5$$

$$NOx = A_0 + A_1 s + A_2 s^2 + A_3 s^3 + A_4 s^4$$

```
GROUP= 1
HC=     0.22461E+01   -0.29097E+00   0.15889E-01   -0.47249E-03   0.69408E-05   -0.39280E-07
CO=     0.18198E+01   -0.25466E+00   0.15235E-01   -0.48740E-03   0.75821E-05   -0.44951E-07
NOX=    0.24442E+01   -0.25011E+00   0.13829E-01   -0.28703E-03   0.20758E-05    0.0
-----------------------------------------------------------------------------------------
GROUP= 2
HC=     0.23103E+01   -0.28957E+00   0.15299E-01   -0.44669E-03   0.64818E-05   -0.36346E-07
CO=     0.23399E+01   -0.29698E+00   0.16007E-01   -0.47740E-03   0.70675E-05   -0.40398E-07
NOX=    0.16863E+01   -0.11830E+00   0.65497E-02   -0.13714E-03   0.10085E-05    0.0
-----------------------------------------------------------------------------------------
GROUP= 3
HC=     0.21656E+01   -0.26999E+00   0.14422E-01   -0.43364E-03   0.65074E-05   -0.37810E-07
CO=     0.24415E+01   -0.29147E+00   0.14295E-01   -0.38785E-03   0.52978E-05   -0.28244E-07
NOX=    0.11265E+01   -0.39340E-01   0.26864E-02   -0.60802E-04   0.47729E-06    0.0
-----------------------------------------------------------------------------------------
```

(Illustration 11 cont'd)

```
GROUP= 4
HC=     0.23973E+01  -0.29998E+00   0.16135E-01  -0.48749E-03   0.72909E-05  -0.41977E-07
CO=     0.24655E+01  -0.30502E+00   0.16050E-01  -0.47397E-03   0.69908E-05  -0.39976E-07
NOX=    0.12268E+01  -0.44498E-01   0.26248E-02  -0.56715E-04   0.43429E-06   0.0
------------------------------------------------------------------------------------------
GROUP= 5
HC=     0.24087E+01  -0.30819E+00   0.16817E-01  -0.50684E-03   0.75385E-05  -0.43160E-07
CO=     0.27780E+01  -0.31913E+00   0.15318E-01  -0.42233E-03   0.58495E-05  -0.31497E-07
NOX=    0.10174E+01  -0.11896E-01   0.91437E-03  -0.21574E-04   0.18230E-06   0.0
------------------------------------------------------------------------------------------
GROUP= 6
HC=     0.22322E+01  -0.28499E+00   0.15383E-01  -0.45674E-03   0.67349E-05  -0.38380E-07
CO=     0.27890E+01  -0.32711E+00   0.16294E-01  -0.46757E-03   0.67191E-05  -0.37440E-07
NOX=    0.98760E+00  -0.19567E-01   0.16964E-02  -0.40400E-04   0.32800E-06   0.0
------------------------------------------------------------------------------------------
GROUP= 7
HC=     0.22522E+01  -0.28778E+00   0.15682E-01  -0.47318E-03   0.70795E-05  -0.40846E-07
CO=     0.27074E+01  -0.33131E+00   0.17618E-01  -0.53858E-03   0.81740E-05  -0.47780E-07
NOX=    0.11592E+01  -0.44454E-01   0.29643E-02  -0.66899E-04   0.52236E-06   0.0
------------------------------------------------------------------------------------------
GROUP= 8
HC=     0.20278E+01  -0.27305E+00   0.15358E-01  -0.46030E-03   0.67853E-05  -0.38488E-07
CO=     0.18692E+01  -0.27668E+00   0.17233E-01  -0.55828E-03   0.87168E-05  -0.51698E-07
NOX=    0.18866E+01  -0.16129E+00   0.90499E-02  -0.18561E-03   0.13256E-05   0.0
------------------------------------------------------------------------------------------
GROUP= 9
HC=     0.21506E+01  -0.28362E+00   0.15384E-01  -0.44214E-03   0.62873E-05  -0.34631E-07
CO=     0.18213E+01  -0.27205E+00   0.17030E-01  -0.55202E-03   0.86254E-05  -0.51144E-07
NOX=    0.15578E+01  -0.11303E+00   0.67183E-02  -0.14341E-03   0.10608E-05   0.0
------------------------------------------------------------------------------------------
GROUP=10
HC=     0.22302E+01  -0.29365E+00   0.16236E-01  -0.48415E-03   0.71159E-05  -0.40286E-07
CO=     0.20142E+01  -0.29519E+00   0.18635E-01  -0.62161E-03   0.99366E-05  -0.59978E-07
NOX=    0.20452E+01  -0.19401E+00   0.11074E-01  -0.23175E-03   0.16837E-05   0.0
------------------------------------------------------------------------------------------
```

(Illustration 11 cont'd)

```
GROUP=11
HC=     0.21223E+01   -0.29107E+00    0.16909E-01   -0.52615E-03    0.80271E-05   -0.47012E-07
CO=     0.20453E+01   -0.31062E+00    0.20485E-01   -0.70853E-03    0.11621E-04   -0.71569E-07
NOX=    0.16326E+01   -0.12186E+00    0.70302E-02   -0.14629E-03    0.10614E-05    0.0
FE=     0.35076E-01    0.87843E-01   -0.27727E-02    0.47466E-04   -0.33220E-06    0.0

GROUP=12
HC=     0.21536E+01   -0.28345E+00    0.15695E-01   -0.46976E-03    0.69383E-05   -0.39471E-07
CO=     0.23187E+01   -0.34115E+00    0.20945E-01   -0.66589E-03    0.10223E-04   -0.59827E-07
NOX=    0.14482E+01   -0.12244E+00    0.79502E-02   -0.17108E-03    0.12578E-05    0.0
-----------------------------------------------------------------------------------------------
GROUP=13
HC=     0.20735E+01   -0.28935E+00    0.17304E-01   -0.55471E-03    0.86420E-05   -0.51311E-07
CO=     0.25752E+01   -0.32889E+00    0.18975E-01   -0.62826E-03    0.10092E-04   -0.61273E-07
NOX=    0.24597E+00    0.84195E-01   -0.34084E-02    0.62988E-04   -0.41397E-06    0.0
-----------------------------------------------------------------------------------------------
GROUP=14
HC=     0.23495E+01   -0.30496E+00    0.16842E-01   -0.50962E-03    0.75952E-05   -0.43496E-07
CO=     0.26845E+01   -0.33282E+00    0.17628E-01   -0.52412E-03    0.77222E-05   -0.43702E-07
NOX=    0.12817E+01   -0.80487E-01    0.53574E-02   -0.11889E-03    0.90106E-06    0.0
-----------------------------------------------------------------------------------------------
GROUP=15
HC=     0.21134E+01   -0.28568E+00    0.16318E-01   -0.50079E-03    0.75507E-05   -0.43719E-07
CO=     0.21549E+01   -0.32912E+00    0.21011E-01   -0.68906E-03    0.10839E-04   -0.64712E-07
NOX=    0.15345E+01   -0.12567E+00    0.78592E-02   -0.16943E-03    0.12549E-05    0.0
-----------------------------------------------------------------------------------------------
GROUP=16
HC=     0.21194E+01   -0.29863E+00    0.18447E-01   -0.61654E-03    0.99206E-05   -0.60402E-07
CO=     0.25456E+01   -0.36295E+00    0.23277E-01   -0.81504E-03    0.13623E-04   -0.85591E-07
NOX=    0.70481E+00    0.38153E-01   -0.17391E-02    0.32614E-04   -0.20385E-06    0.0
-----------------------------------------------------------------------------------------------
GROUP=17
HC=     0.26838E+01   -0.34463E+00    0.19542E-01   -0.62572E-03    0.97844E-05   -0.58337E-07
CO=     0.28393E+01   -0.36876E+00    0.21078E-01   -0.67644E-03    0.10627E-04   -0.63641E-07
NOX=    0.78384E+00    0.32855E-03    0.10603E-02   -0.31935E-04    0.29039E-06    0.0
-----------------------------------------------------------------------------------------------
GROUP=18
HC=     0.23954E+01   -0.33578E+00    0.21161E-01   -0.73155E-03    0.12072E-04   -0.74857E-07
CO=     0.24875E+01   -0.39156E+00    0.27072E-01   -0.97618E-03    0.16527E-04   -0.10432E-06
NOX=    0.94213E+00   -0.42324E-01    0.38625E-02   -0.93985E-04    0.75388E-06    0.0
-----------------------------------------------------------------------------------------------
```

Illustration 12

Selected Speed Correction Factors - Warm Operation

Hydrocarbon

Average Speed

GROUP	5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000	55.000	60.000
1	3.107	1.679	1.201	0.987	0.858	0.761	0.684	0.629	0.597	0.585	0.571	0.516
2	3.297	1.749	1.224	0.986	0.844	0.740	0.659	0.600	0.565	0.547	0.530	0.482
3	3.083	1.708	1.219	0.986	0.841	0.733	0.650	0.592	0.556	0.534	0.503	0.429
4	3.470	1.808	1.246	0.984	0.821	0.700	0.606	0.538	0.497	0.472	0.445	0.381
5	3.419	1.773	1.231	0.985	0.834	0.720	0.630	0.565	0.526	0.504	0.479	0.414
6	3.123	1.695	1.208	0.987	0.853	0.754	0.677	0.622	0.591	0.576	0.557	0.495
7	3.160	1.709	1.215	0.986	0.845	0.740	0.658	0.600	0.567	0.551	0.529	0.460
8	2.700	1.548	1.160	0.990	0.889	0.811	0.748	0.703	0.681	0.678	0.672	0.616
9	2.903	1.600	1.170	0.990	0.891	0.819	0.762	0.720	0.699	0.694	0.691	0.649
10	3.039	1.649	1.190	0.988	0.867	0.775	0.702	0.649	0.619	0.609	0.596	0.538
11	2.798	1.571	1.168	0.989	0.877	0.788	0.716	0.667	0.644	0.638	0.617	0.525
12	2.928	1.623	1.184	0.988	0.871	0.781	0.709	0.659	0.632	0.624	0.612	0.553
13	2.705	1.548	1.165	0.989	0.871	0.773	0.694	0.640	0.616	0.610	0.589	0.493
14	3.276	1.726	1.216	0.986	0.844	0.736	0.650	0.589	0.554	0.538	0.519	0.456
15	2.815	1.582	1.172	0.989	0.876	0.788	0.717	0.669	0.646	0.641	0.628	0.553
16	2.763	1.575	1.181	0.987	0.848	0.729	0.635	0.573	0.543	0.531	0.497	0.383
17	3.963	1.931	1.285	0.981	0.784	0.635	0.523	0.446	0.401	0.373	0.337	0.258
18	3.194	1.708	1.228	0.984	0.803	0.653	0.540	0.468	0.432	0.414	0.373	0.260

(Illustration 12 cont'd)

Carbon Monoxide

GROUP	Average Speed											
	5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000	55.000	60.000
1	2.389	1.463	1.142	0.991	0.889	0.803	0.733	0.686	0.665	0.663	0.647	0.558
2	3.319	1.751	1.225	0.986	0.841	0.734	0.650	0.592	0.557	0.539	0.518	0.454
3	3.656	1.856	1.251	0.985	0.837	0.738	0.663	0.608	0.572	0.554	0.542	0.515
4	3.621	1.844	1.253	0.984	0.823	0.707	0.619	0.556	0.517	0.493	0.465	0.399
5	4.554	2.120	1.329	0.979	0.781	0.644	0.543	0.469	0.418	0.384	0.358	0.323
6	4.511	2.103	1.326	0.979	0.778	0.637	0.533	0.457	0.407	0.374	0.345	0.299
7	4.174	2.003	1.299	0.975	0.776	0.633	0.526	0.453	0.406	0.375	0.341	0.273
8	2.345	1.418	1.121	0.992	0.905	0.827	0.760	0.717	0.703	0.711	0.701	0.600
9	2.277	1.395	1.113	0.993	0.913	0.841	0.780	0.743	0.737	0.755	0.756	0.662
10	2.541	1.488	1.149	0.990	0.873	0.770	0.684	0.629	0.608	0.608	0.589	0.478
11	2.516	1.474	1.148	0.989	0.863	0.746	0.651	0.591	0.568	0.566	0.534	0.397
12	2.885	1.540	1.149	0.991	0.891	0.804	0.729	0.677	0.657	0.658	0.643	0.538
13	3.791	1.916	1.291	0.980	0.771	0.612	0.496	0.420	0.378	0.355	0.324	0.246
14	4.056	1.950	1.281	0.982	0.804	0.675	0.577	0.510	0.470	0.451	0.436	0.391
15	2.599	1.459	1.127	0.992	0.900	0.814	0.739	0.691	0.675	0.681	0.661	0.530
16	3.384	1.744	1.237	0.983	0.795	0.641	0.527	0.458	0.427	0.410	0.360	0.227
17	4.239	1.980	1.293	0.981	0.782	0.634	0.525	0.454	0.415	0.395	0.364	0.278
18	2.988	1.580	1.183	0.986	0.821	0.671	0.557	0.493	0.475	0.478	0.434	0.265

Nitric Oxide

GROUP	Average Speed											
	5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000	55.000	60.000
1	1.505	1.060	0.941	1.010	1.161	1.319	1.440	1.511	1.551	1.608	1.764	2.129
2	1.242	1.031	0.974	1.004	1.074	1.146	1.203	1.239	1.265	1.306	1.404	1.615
3	0.990	0.946	0.960	1.004	1.058	1.109	1.150	1.182	1.213	1.258	1.340	1.489
4	1.063	0.992	0.980	1.002	1.038	1.075	1.105	1.129	1.152	1.189	1.257	1.384
5	0.978	0.970	0.981	1.002	1.026	1.049	1.070	1.091	1.115	1.151	1.208	1.298
6	0.927	0.924	0.956	1.004	1.056	1.102	1.141	1.173	1.206	1.250	1.323	1.445
7	1.003	0.949	0.960	1.004	1.059	1.110	1.150	1.180	1.207	1.250	1.331	1.483
8	1.284	1.006	0.944	1.008	1.128	1.255	1.359	1.429	1.477	1.531	1.641	1.877
9	1.143	0.966	0.944	1.007	1.105	1.200	1.275	1.323	1.358	1.406	1.511	1.733
10	1.324	0.997	0.930	1.010	1.152	1.297	1.410	1.480	1.524	1.582	1.721	2.031
11	1.181	0.981	0.946	1.007	1.109	1.214	1.300	1.361	1.407	1.462	1.570	1.786
12	1.014	0.860	0.887	1.012	1.174	1.330	1.454	1.542	1.606	1.678	1.810	2.070
13	0.589	0.806	0.934	1.004	1.043	1.070	1.097	1.132	1.175	1.221	1.258	1.268
14	0.999	0.903	0.924	1.008	1.112	1.208	1.282	1.332	1.369	1.421	1.526	1.736
15	1.082	0.907	0.909	1.010	1.148	1.280	1.382	1.452	1.501	1.564	1.691	1.955
16	0.856	0.943	0.986	1.001	1.002	1.000	1.002	1.014	1.036	1.067	1.103	1.136
17	0.808	0.864	0.934	1.006	1.069	1.121	1.161	1.193	1.226	1.274	1.353	1.486
18	0.816	0.819	0.897	1.009	1.124	1.222	1.294	1.344	1.386	1.446	1.560	1.777

(Illustration 12 cont'd)

Hydrocarbon

Average Speed

GROUP	6.000	11.000	16.000	21.000	26.000	31.000	36.000	41.000	46.000	51.000	56.000	61.000
1	2.662	1.544	1.146	0.957	0.837	0.744	0.671	0.621	0.594	0.583	0.565	0.495
2	2.816	1.601	1.163	0.953	0.821	0.722	0.645	0.591	0.560	0.544	0.535	0.464
3	2.663	1.573	1.160	0.952	0.817	0.715	0.637	0.583	0.551	0.529	0.493	0.406
4	2.951	1.650	1.180	0.946	0.794	0.679	0.590	0.528	0.491	0.468	0.437	0.361
5	2.901	1.620	1.168	0.950	0.809	0.700	0.615	0.555	0.520	0.500	0.471	0.393
6	2.680	1.558	1.151	0.956	0.832	0.737	0.664	0.614	0.587	0.573	0.550	0.474
7	2.710	1.571	1.156	0.954	0.822	0.722	0.644	0.592	0.563	0.548	0.520	0.437
8	2.343	1.438	1.116	0.967	0.872	0.797	0.737	0.697	0.680	0.679	0.667	0.594
9	2.497	1.477	1.123	0.966	0.875	0.807	0.752	0.714	0.697	0.694	0.687	0.631
10	2.604	1.519	1.138	0.960	0.847	0.759	0.689	0.641	0.616	0.607	0.589	0.516
11	2.413	1.457	1.122	0.964	0.858	0.772	0.704	0.661	0.642	0.636	0.606	0.494
12	2.522	1.499	1.134	0.961	0.851	0.765	0.698	0.652	0.629	0.623	0.606	0.531
13	2.343	1.440	1.121	0.963	0.850	0.756	0.681	0.633	0.614	0.609	0.578	0.460
14	2.788	1.582	1.158	0.953	0.821	0.717	0.636	0.580	0.550	0.535	0.511	0.434
15	2.430	1.466	1.125	0.963	0.857	0.772	0.705	0.662	0.644	0.640	0.620	0.536
16	2.389	1.464	1.133	0.957	0.823	0.708	0.620	0.564	0.540	0.527	0.482	0.348
17	3.309	1.748	1.209	0.936	0.751	0.610	0.505	0.435	0.395	0.368	0.325	0.335
18	2.717	1.573	1.169	0.945	0.770	0.627	0.522	0.458	0.428	0.410	0.358	0.338

Carbon Monoxide

Average Speed

GROUP	6.000	11.000	16.000	21.000	26.000	31.000	36.000	41.000	46.000	51.000	56.000	61.000
1	2.105	1.373	1.104	0.968	0.871	0.787	0.721	0.679	0.664	0.663	0.637	0.536
2	2.829	1.602	1.164	0.952	0.817	0.715	0.637	0.583	0.552	0.536	0.510	0.473
3	3.096	1.685	1.181	0.949	0.815	0.721	0.650	0.599	0.567	0.551	0.539	0.504
4	3.063	1.678	1.184	0.946	0.797	0.687	0.604	0.546	0.511	0.488	0.456	0.378
5	3.784	1.896	1.239	0.932	0.750	0.622	0.526	0.457	0.410	0.379	0.353	0.313
6	3.745	1.882	1.237	0.932	0.746	0.613	0.515	0.446	0.399	0.369	0.338	0.385
7	3.482	1.804	1.217	0.929	0.744	0.609	0.509	0.441	0.399	0.370	0.331	0.253
8	2.054	1.333	1.088	0.973	0.889	0.812	0.749	0.712	0.704	0.712	0.691	0.563
9	2.001	1.314	1.082	0.975	0.898	0.827	0.770	0.739	0.739	0.758	0.748	0.634
10	2.208	1.392	1.110	0.965	0.852	0.751	0.670	0.622	0.607	0.608	0.577	0.440
11	2.183	1.381	1.110	0.963	0.839	0.725	0.636	0.583	0.567	0.564	0.517	0.355
12	2.447	1.425	1.107	0.969	0.873	0.788	0.716	0.671	0.656	0.658	0.632	0.501
13	3.196	1.742	1.215	0.933	0.735	0.585	0.477	0.409	0.373	0.351	0.313	0.223
14	3.383	1.759	1.204	0.940	0.775	0.653	0.562	0.500	0.465	0.449	0.431	0.375
15	2.228	1.361	1.092	0.972	0.862	0.797	0.727	0.685	0.676	0.682	0.646	0.466
16	2.848	1.601	1.176	0.942	0.762	0.615	0.510	0.449	0.423	0.405	0.341	0.193
17	3.500	1.783	1.214	0.935	0.749	0.609	0.508	0.444	0.410	0.391	0.352	0.253
18	2.515	1.465	1.137	0.952	0.789	0.644	0.540	0.486	0.475	0.476	0.411	0.221

(Illustration 12 cont'd)

Nitric Oxide

Average Speed

GROUP	6.000	11.000	16.000	21.000	26.000	31.000	36.000	41.000	46.000	51.000	56.000	61.000
1	1.382	1.015	0.943	1.036	1.194	1.347	1.458	1.521	1.559	1.628	1.816	2.239
2	1.184	1.010	0.975	1.017	1.089	1.159	1.211	1.244	1.271	1.330	1.436	1.677
3	0.975	0.945	0.967	1.015	1.069	1.118	1.157	1.187	1.220	1.271	1.364	1.530
4	1.043	0.986	0.983	1.009	1.046	1.081	1.110	1.133	1.158	1.199	1.277	1.419
5	0.975	0.971	0.985	1.007	1.030	1.053	1.074	1.095	1.121	1.160	1.223	1.321
6	0.923	0.929	0.965	1.014	1.065	1.111	1.148	1.180	1.213	1.262	1.343	1.478
7	0.985	0.947	0.967	1.015	1.070	1.119	1.157	1.185	1.214	1.262	1.354	1.525
8	1.206	0.980	0.949	1.029	1.154	1.278	1.376	1.440	1.486	1.546	1.675	1.946
9	1.092	0.952	0.951	1.025	1.125	1.217	1.286	1.331	1.365	1.421	1.544	1.798
10	1.232	0.967	0.937	1.036	1.183	1.323	1.427	1.490	1.533	1.601	1.766	2.124
11	1.124	0.964	0.953	1.025	1.130	1.233	1.314	1.371	1.416	1.478	1.602	1.849
12	0.964	0.854	0.906	1.043	1.207	1.358	1.475	1.556	1.618	1.698	1.849	2.145
13	0.642	0.837	0.951	1.014	1.049	1.075	1.103	1.140	1.184	1.229	1.263	1.264
14	0.967	0.900	0.937	1.028	1.133	1.225	1.294	1.340	1.378	1.436	1.557	1.797
15	1.028	0.896	0.924	1.036	1.175	1.303	1.399	1.462	1.511	1.582	1.731	2.031
16	0.878	0.954	0.990	1.001	1.001	1.000	1.004	1.017	1.042	1.074	1.110	1.141
17	0.817	0.877	0.949	1.019	1.081	1.130	1.168	1.199	1.234	1.287	1.375	1.521
18	0.808	0.830	0.918	1.033	1.145	1.238	1.306	1.352	1.396	1.463	1.594	1.838

Illustration 13

Light Duty Vehicle Hydrocarbon Correction Factors for Ambient Temperature and/or Average Speed and/or % Hot Start/% Cold Start Driving which differ from the FTP Assumptions*

Model Year	Correction Factor**
pre-1968	$[w(\exp(2.9310-.014779t) + .673+.569A)(v_{2,s_1}/.821) + x(4.75+.393A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(5.69+.471A)(v_{g,s_2}/v_{g,16})]/(5.67+.47A)$
1968-74	$[w(\exp(2.9310-.014779t) - 2.41+.863A)(v_{2,s_1}/.821) + x(2.43+.555A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(2.61+.597A)(v_{g,s_2}/v_{g,16})]/(2.8+.64A)$
1975 Federal	$[w(\exp(2.4339-.023591t) + .623+.301A)(v_{2,s_1}/.821) + x(1.11+.284A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(1.05+.270A)(v_{g,s_2}/v_{g,16})]/(1.38+.28A)$
1975 California	$[w(\exp(1.9934-.022269t) - .032+.445A)(v_{2,s_1}/.821) + x(.497+.357A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(.243+.175A)(v_{g,s_2}/v_{g,16})]/(.54+.28A)$

* FTP assumptions are outlined in Table I.1.

** w = fraction of total miles which are driven in cold start condition,

x = fraction of total miles which are driven in hot start condition,

t = ambient temperature (°F),

A = vehicle age minus 1, in years,

g = index for model year-city groups for which average speed data were available ($g = 1, 2, \ldots, 18$),

s_i = average speed (miles per hour) in bag i, $i = 1,2,3$,

$v_{(\ )}/v_{(\ )}$ = bag-specific speed correction factor (.821 equals $v_{2,26}$),

exp = exponential function, base e.

These correction factors are applicable to ambient temperatures of 0° to 110°F, vehicle ages of 1 to 10 years, average vehicle speeds of 5 to 60 mph, and to all combinations of % hot start/% cold start driving. The incorporation of the appropriate $v_{g,s}$ terms (calculated from Table II.13) in the above equations would yield a correction factor for each of the 19 model year-city groups for which data were analyzed. Table II.4 provides the method for combining the basic equations provided in the above table with the appropriate $v_{g,s}$ terms in order to perform calculations without the aid of a computer.

Illustration 14

Light Duty Vehicle Carbon Monoxide Correction Factors for Ambient Temperature and/or Average Speed and/or % Hot Start/% Cold Start Driving which differ from the FTP Assumptions*

Model Year	Correction Factor**
pre-1968	$[w(\exp(5.6548-.015965t) - 14.74+9.62A)(v_{2,s_1}/.817) + x(42.84+5.76A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(57.57+7.74A)(v_{g,s_2}/v_{g,16})]/(56.43+7.59A)$
1968-74	$[w(\exp(5.6548-.015965t) - 33.89+9.77A)(v_{2,s_1}/.817) + x(25.26+4.71A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(35.9+6.70A)(v_{g,s_2}/v_{g,16})]/(36.4+6.79A)$
1975 Federal	$[w(\exp(5.5460-.028945t) + 11.29+4.24A)(v_{2,s_1}/.817) + x(15.85+2.34A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(21.17+3.13A)(v_{g,s_2}/v_{g,16})]/(23.7+3.14A)$
1975 California	$[w(\exp(4.2391-.017522t) - .20+6.99A)(v_{2,s_1}/.817) + x(4.12+2.20A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(3.96+2.12A)(v_{g,s_2}/v_{g,16})]/(6.98+3.14A)$

* FTP assumptions are outlined in Table I.1.

** w = fraction of total miles which are driven in cold start condition,

x = fraction of total miles which are driven in hot start condition,

t = ambient temperature (°F),

A = vehicle age minus 1, in years,

g = index for model year-city groups for which average speed data were available ($g = 1, 2, \ldots, 18$),

s_i = average speed (miles per hour) in bag i, $i = 1,2,3$,

$v_{(\ )}/v_{(\ )}$ = bag-specific speed correction factor (.817 equals $v_{2,26}$).

exp = exponential function, base e.

These correction factors are applicable to ambient temperatures of 0° to 110°F, vehicle ages of 1 to 10 years, average vehicle speeds of 5 to 60 mph, and to all combinations of % hot start/% cold start driving. The incorporation of the appropriate $v_{g,s}$ terms (calculated from Table II.13) in the above equations would yield a correction factor for each of the 19 model year-city groups for which data were analyzed. Table II.4 provides the method for combining the basic equations provided in the above table with the appropriate $v_{g,s}$ terms in order to perform calculations without the aid of a computer.

Illustration 15

Light Duty Vehicle Oxides of Nitrogen Correction Factors for Average Speed and/or % Hot Start/% Cold Start Driving which differ from the FTP Assumptions*

Model Year	Correction Factor **
pre-1968	$1.14\ w\ (v_{2,s_1}/1.089) + 1.25\ x(v_{g,s_3}/v_{g,26}) + 0.81(1-w-x)(v_{g,s_2}/v_{g,16})$
1968-74	$1.16\ w\ (v_{2,s_1}/1.089) + 1.26\ x(v_{g,s_3}/v_{g,26}) + 0.80(1-w-x)(v_{g,s_2}/v_{g,16})$
1975 Federal	$[w(3.26 + .335A)(v_{2,s_1}/1.089) + x(2.99 + .184A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(1.89 + .116A)(v_{g,s_2}/v_{g,16})]/(2.47 + .18A)$
1975 California	$[w(3.05 + .318A)(v_{2,s_1}/1.089) + x(2.88 + .180A)(v_{g,s_3}/v_{g,26}) + (1-w-x)(2.01 + .126A)(v_{g,s_2}/v_{g,16})]/(2.46 + .18A)$

* FTP assumptions are outlined in Table I.1.

** w = fraction of total miles which are driven in cold start condition,

x = fraction of total miles which are driven in hot start condition,

A = vehicle age minus 1, in years,

g = index for model year-city groups for which average speed data were available (g = 1, 2,...,18),

s_i = average speed (miles per hour) in bag i, i = 1,2,3,

$v_{(\ )}/v_{(\ )}$ = bag-specific speed correction factor (1.089 equals $v_{2,26}$).

These correction factors are applicable to ambient temperatures of 0° to 110°F, vehicle ages of 1 to 10 years, average vehicle speeds of 5 to 60 mph, and to all combinations of % hot start/% cold start driving. The incorporation of the appropriate $v_{g,s}$ terms (calculated from Table II.13) in the above equations would yield a correction factor for each of the 19 model year-city groups for which data were analyzed. Table II.4 provides the method for combining the basic equations provided in the above table with the appropriate $v_{g,s}$ terms in order to perform calculations without the aid of a computer.

LAND USE BASED EMISSIONS FACTORS

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

Frank Benesh
Environmental Planner
GCA/Technology Division
Bedford, Massachusetts

Thomas McCurdy
Community Planner
Land Use Planning Office
Strategies and Air Standards Division
U.S. Environmental Protection Agency

ABSTRACT OF "LAND USE BASED EMISSION FACTORS"

A set of land use based emission factors were developed for five criteria pollutants and thirteen land use types. The pollutants are particulates, sulfur oxides, carbon monoxide, total hydrocarbons, and nitrogen oxides; the land uses investigated were five classes of residential (detached single family, attached single family, mobile homes, lowrise multifamily, and highrise multifamily), retail commercial, wholesale commercial, transient lodging, offices, hospitals, cultural buildings, churches, and schools. Units of the emission factors for heating degree day or compressor operating hour. Non-residential emission factor units are given in pounds of pollutant per square feet of floor area per heating or cooling degree day. Emission factors are also presented in SI units.

Methods used to develop the emission factors are discussed in the paper. The factors are applied to one land use type to determine what project size (in terms of number of dwelling units) would be a "major source" under EPA's 1976 Interpretative Ruling on the location of new sources within non-attainment areas. This application indicates that land use based emission factors are easy-to-use.

INTRODUCTION

Any air resource management approach that includes evaluation of community land use plans for their ambient air quality impacts requires that estimates of emissions be devised for the time period of analysis. Normally this is a time consuming and laborious process as evidenced by the amount of work that went into the emission inventories discussed at this conference. It is a process well beyond the limited expertise and budget of most planning agencies in this country. Past EPA attempts to standardize and simplify the procedure, such at its Volume 7 and 13 of the Air Quality Maintenance Planning Analysis guidelines (1), are still very complex and tedious. (In fact, an effort is currently underway to determine if the procedure should be computerized or not (2).) If routine evaluation of land use plans for air quality impacts is to become a reality, a method has to be devised to reduce the complexity and labor involved -- especially if urban planners are the ones who will be doing the evaluation (3).

The Land Use Planning Office of EPA's Strategies and Air Standards Division has long been interested in developing easy-to-use land use oriented emission factors. The Office sponsored two projects in 1972-1973 that developed and used land use based emission factors: the "Air Pollution-Land Use Planning Project" with Argonne National Laboratories (4) and the "Hackensack Meadowlands Air Pollution Study" with a private contractor (5).*

These two efforts treated emissions as a function of land area, viz:

$$\text{emission factor} = \frac{\text{emissions}}{\text{unit land area}}$$

Because space heating, process emissions, and the like occur indoors and have no known consistent relationship with land area per se, the above formulated emission factor is incomplete because another piece of information is needed to use it -- density of development (building area per lot area). To avoid this problem, land use based emission factors based on building area were developed as part of the "Growth Effects of Major Land Use Projects" (GEMLUP) effort (9). These building area emission factors are the subject of this paper.**

RELATIONSHIP WITH CONVENTIONAL EMISSION FACTORS

Reference 4 has shown the lack of ability of land use based emission factors to adequately predict emissions of large industrial sources, i.e., point sources. (It is also shown that other economic and planning indicators such as employment and output are also incapable of predicting industrial point source emissions. This is due, in part, to the variability of emission rates within even fine industrial categories such as four digit SIC codes). Thus, large industrial sources must be treated individually when using land use based emission factors, as is the case when conventional emission factors are utilized in an emission inventory.

---

*A critical review of land use emission factors developed in these projects is found in references 6-7. An elaboration of Hackensack Meadowland factors is found in reference 8. How land use data can be used to improve area source emission inventories is contained in reference 27.

**A land area emission factor can easily be derived from a building area factor by multiplying the latter by "floor area ratio," or FAR, which is a density measure with units of building floor area per unit lot area. This ratio has been standardized for zoning purposes by the Federal Housing Administration, and is part of a larger scheme to relate building areas with open space and parking. See reference 10 for additional information.

Land use based emission factors can be expected to handle area source emissions adequately. In the special (and hypothetical) case where the land use categories are identical to the area source emission categories in a conventional emission inventory, an emission inventory prepared with land use based emission factors will be exactly equivalent to a conventially prepared inventory. In fact, one method of estimating locally specific land use based emission factors is through a regression analysis of a conventionally prepared inventory, such as was done by the California Air Resource Board (30). Depending on the data available in a specific application, land use based emission factors may be able to provide a more accurate emission inventory (both in terms of aggregate emissions and their spatial distribution) then the conventional approach. The classification scheme employed in the land use inventory and the availability of accurate fuel consumption data for the region of interest are principal determinants of which approach will be more accurate. The utilization of land use based emission factors would appear to be less time consuming in all instances.

GEMLUP APPROACH TO DEVELOPING LAND USE BASED EMISSION FACTORS

Land use based emission factors are usually disaggregated into two components, an activity factor (i.e., fuel throughput, etc., per unit floor area), and the standard emission factor (i.e., emissions per unit fuel). For example, in the case of fuel oil space heating consumption, this would be:

$$\frac{\text{emissions (gr)}}{\text{floor area } (10^3 \text{ ft}^2)} = \frac{\text{oil consump. (gals)}}{\text{floor area } (10^3 \text{ ft}^2)} * \frac{\text{emissions (gr)}}{\text{oil consump. (gals)}}$$

Given this approach, a complete set of land use based emission factors would consist of an n-dimensional array with specific values given for a pollutant species, fuel or process type, building category, and, in some cases, energy requirements (e.g., region of the country).

Ignoring solvent evaporation, solid waste disposal, and other miscellaneous emissions*, an energy consumption related emission factor can be generalized as follows:

$$\frac{\text{emissions}_{i,j,k}}{\text{ft}^2 * \text{year}} = \left[\left(\frac{\text{Btu}_i}{\text{ft}^2 * \text{year}} + \frac{\text{Btu}_i}{\text{ft}^2 * \text{ht.d.d.}} + \frac{\text{Btu}_i}{\text{ft}^2 * \text{cl.d.d.}}\right) * \frac{1}{\text{heat content}_i} * \frac{1}{\text{seasonal efficiency}} * \frac{\text{emissions}}{\text{unit fuel}_i}\right]_k$$

---

*Emissions from these sources were not considered in the GEMLUP project, because (1) there is limited information about their characteristics, and (2) they may be expected to display a lot of variation in per unit floor area emissions among parts of the country. However, the emission factor structure discussed above is amenable to their inclusion.

Where:

ht.d.d. = heating degree days per year

cl.d.d. = cooling degree days per year

and for a particular fuel type i, pollutant species j and building category k.

The fourth term in this equation, emissions per unit fuel, is the commonly used values determined directly from EPA's Compilation of Air Pollutant Emission Factors (11). Hence, focus of the GEMLUP project was on generating the first three terms (i.e., the activity factor).

The activity factor identifies fuel consumption per building floor area given a number of heating and cooling degree days. The heat content of fuel in British thermal units is approximately constant and is well known (12). It does display some variation for every fuel, especially for natural gas in different regions of the country (13).

Efficiency values for building types and fuels are less well known. Efficiency can be defined in a variety of ways, and is used to account for differences in the amount of energy consumed by a building depending on the fuel type selected to provide that energy. This is not heating unit efficiency, which is measured at full load/steady state operation. Thus, it does not account for rapid on and off cycling associated with the typical oversized furnace. Nor (in the case of gas furnaces) does it measure the pilot light fuel consumption when the furnace is off.

The desired efficiency measure for GEMLUP purposes was the ratio of heat loss from a structure to the energy input to the structure. This is variously defined as efficiency of utilization or seasonal efficiency. However, even with this definition of efficiency, there is some disagreement in the literature over what are appropriate values to use.

The term in brackets, the energy requirement per square foot and per square foot degree day, represents building energy requirements. It is divided into three components:

1. Process use of energy that is not related to climate, such as:

Lighting	Water heating equipment
Elevators	Cooking equipment
Refrigeration	Ventilation

2 Energy requirements for space heating as a function of heating degree days.

3. Energy requirements for air conditioning as a function of cooling degree days.

The energy requirement factor, the efficiency of utilization, and the standard emission factors are all estimates of the mean of population values and can be expected to display a large variation. In general, these factors are not precise indicators of energy requirement, efficiency, or emissions of a single source. They are more valid when applied to a large number of sources. Sources of variation in the energy requirement and efficiency factors are discussed in the GEMLUP report (9) and will not be discussed here.

The critical element in the development of land use based emission factors is estimating energy requirements per square foot for various building types; the rest of the information needed to develop the factors is generally available.

Much of the existing literature on energy consumption in buildings is not applicable to the development of energy requirement factors. Most of it is devoted to predicting energy consumption of a single structure. The literature that was applicable to the GEMLUP study fell into two classes: (1) typical energy consumption data for building categories based on engineering estimates, and (2) average energy consumption information from a sample of structures in a particular building category. Both classes of literature were used in GEMLUP analyses with slightly more emphasis given to the latter category, particularly utility company surveys of customer energy utilization. Where conflicting data were presented, a compromise value was chosen that seemed to represent an "average" situation.

Not all of the data come from secondary sources. Regression analyses of office building energy usage were undertaken as part of the GEMLUP project. Input data for the analyses came from a Building Owners and Managers Association annual survey of energy use (24). The regressions yielded very low coefficients of determination, even though various combinations of independent variables were used (9).

LAND USE BASED EMISSION FACTORS

Land use based emission factors for uncontrolled single family residences are presented in Table 1. Similar factors for all other

TABLE 1

SINGLE FAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

	Pound of pollutant (or kilowatt-hours) per measure						
	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	3.8	dwelling unit°ht.d.d.
Gas	2.6×10^{-4}	1.5×10^{-5}	5.1×10^{-4}	2.0×10^{-4}	2.6×10^{-3}	-	dwelling unit°ht.d.d.
Oil	2.2×10^{-3}	$3.2 \times 10^{-2}S$	1.1×10^{-3}	6.6×10^{-4}	2.6×10^{-3}	-	dwelling unit°ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	4.7	dwelling unit°op.hr.
Gas	1.8×10^{-4}	1.1×10^{-5}	3.5×10^{-4}	1.4×10^{-4}	1.8×10^{-3}	-	dwelling unit°op.hr.
Room							
Electricity	-	-	-	-	-	5.1×10^{-1}	a.c. unit°operating hour
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.4 \times 10^{+4}$	dwelling unit°year
Gas	3.0×10^{-1}	1.8×10^{-2}	6.0×10^{-1}	2.4×10^{-1}	3.0	-	dwelling unit°year
Oil	2.5	$3.7 \times 10^{-1}S$	1.2	7.5×10^{-1}	3.0	-	dwelling unit°year
Cooking							
Electricity	-	-	-	-	-	$3.5 \times 10^{+3}$	dwelling unit°year
Gas	1.1×10^{-1}	6.6×10^{-3}	2.2×10^{-1}	8.8×10^{-2}	1.1		dwelling unit°year
Miscellaneous	-	-	-	-	-	$7.9 \times 10^{+3}$	dwelling unit°year

Note: A 1600 square foot dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

land uses investigated in the GEMLUP project are contained in Reference 9. The factors are presented in units of pounds of pollutant emitted per "measure" for oil and gas combustion. For electricity consumption, the factors are in terms of kilowatt-hours per "measure". The measure, depending on the activity involved, may be square foot of building floor area per heating degree day, dwelling unit per year, air conditioner operating hour, etc.

The quantity of secondary, i.e., offsite, emissions occuring due to electricity consumption depends on the nature of the local electric utility generating station. In developing an estimate of secondary emissions caused by a land use type, the local utility should be contacted to determine the proper emission rate. Default values for these emissions have been developed. however, and appear as Table 2. They come from data in references 11,25, and 26.

None of the tables present process emissions for industrial sources. The estimation and use of land use based emission factors for industry presents severe problems. The variation in emissions per square feet of industrial land area, and probably in industrial building area also, is great (4,7). Therefore, GEMLUP industrial emission factors only includes fuel combustion and treats these emissions like area source emissions in a typical emissions inventory. Process emissions have to be obtained separately and added to fuel use emissions.

TABLE 2

TYPICAL EMISSION FACTORS FOR ELECTRIC UTILITIES

Pounds of pollutant emissions per kilowatt hour sold to customer

	PM	SO_x	CO	HC	NO_x
coal	5.23×10^{-3}	$1.53 \times 10^{-2}S$	4.03×10^{-4}	1.21×10^{-4}	2.21×10^{-2}
oil	6.34×10^{-4}	$1.26 \times 10^{-2}S$	2.38×10^{-4}	1.58×10^{-4}	8.32×10^{-3}
gas	1.19×10^{-4}	7.13×10^{-6}	2.02×10^{-4}	1.19×10^{-5}	8.32×10^{-3}

Kilograms of pollutant emissions per joule sold to customer (SI Units)

	PM	SO_x	CO	HC	NO_x
coal	6.59×10^{-10}	$1.93 \times 10^{-9}S$	5.08×10^{-11}	1.52×10^{-11}	2.78×10^{-9}
oil	7.99×10^{-11}	$1.59 \times 10^{-9}S$	3.00×10^{-11}	1.99×10^{-11}	1.05×10^{-9}
gas	1.50×10^{-11}	8.98×10^{-13}	2.55×10^{-11}	1.50×10^{-12}	1.05×10^{-9}

Note: A 33.3% overall plant efficiency is assumed for coal fired plants [34].
A 31.6% overall plant efficiency is assumed for oil and gas fired plants [34].

A 10% transmission loss is assumed [35].

'S' and 'A' represent, respectively, the sulfur and ash percentage of fuel by weight.

TABLE 2
TYPICAL EMISSION FACTORS FOR ELECTRIC UTILITIES

	Pounds of pollutant emissions per kilowatt hour sold to customer				
	PM	SO_x	CO	HC	NO_x
coal	5.23×10^{-3}	$1.53 \times 10^{-2}S$	4.03×10^{-4}	1.21×10^{-4}	2.21×10^{-2}
oil	6.34×10^{-4}	$1.26 \times 10^{-2}S$	2.38×10^{-4}	1.58×10^{-4}	8.32×10^{-3}
gas	1.19×10^{-4}	7.13×10^{-6}	2.02×10^{-4}	1.19×10^{-5}	8.32×10^{-3}

	Kilograms of pollutant emissions per joule sold to customer (SI Units)				
	PM	SO_x	CO	HC	NO_x
coal	6.59×10^{-10}	$1.93 \times 10^{-9}S$	5.08×10^{-11}	1.52×10^{-11}	2.78×10^{-9}
oil	7.99×10^{-11}	$1.59 \times 10^{-9}S$	3.00×10^{-11}	1.99×10^{-11}	1.05×10^{-9}
gas	1.50×10^{-11}	8.98×10^{-13}	2.55×10^{-11}	1.50×10^{-12}	1.05×10^{-9}

Note: A 33.3% overall plant efficiency is assumed for coal fired plants [34].
A 31.6% overall plant efficiency is assumed for oil and gas fired plants [34].

A 10% transmission loss is assumed [35].

'S' and 'A' represent, respectively, the sulfur and ash percentage of fuel by weight.

APPLICATION OF LAND USE BASED EMISSION FACTORS: DETERMINING " MAJOR SOURCES" IN NON-ATTAINMENT AREAS

To illustrate how land use based emission factors can be used, a "real-life" example will be presented. On December 21, 1976 EPA issued "Requirements" (28) and an "Interpretative Ruling" (29) on the location of new sources within non-attainment areas. The Ruling states that a major new source may lcoate in an area with air quality problems only if stringent conditions can be met. The conditions are: emissions are controlled to the "greatest degree possible, "equivalent emission reductions will be obtained from existing sources, and progress toward attaining air quality standards will be achieved (41 FR 55525). A preconstruction review process of all sources emitting 100 tons of pollutant* per year or more (1,000 tons for carbon monoxide) is mandated to implement the ruling. If these "major" sources do not meet the three conditions mentioned above, a State is not allowed to issue a construction permit under 40 CFR 51.18 (41 FR 55525).

In the other Federal Register notice, EPA proposes to lower the "major source" definition down to 50 tons of pollutant* per year (500 tons for carbon monoxide) (41 FR 55559). In other words, facilities emitting 50 tons of most criteria pollutants will be required to undergo new source review and meet the stringent requirements.

---

*The pollutants of interest are particulate matter, sulfur oxides, nitrogen oxides, and non-methane hydrocarbons.

For a private developer of land, a question immediately arises: what size of project will trigger a new source review? Phrased another way, what is the biggest shopping center (or apartment house, etc.) a developer can build without emitting 50 tons per year of SO_x or TSP? Land use based emission factors can be used to answer these questions, and doing so constitutes the example to be shown in the remainder of this paper.

Basically, the answer is obtained by using Table 1 to solve the following simple equation (or ones similar to it):

$$\text{sq ft} = \frac{50\ \text{tons}}{\text{yr}} \bullet \underbrace{\frac{\text{sq ft}}{\text{tons}} \bullet \frac{\text{ht.d.d.}}{}}_{\text{land use based emission factor}} \bullet \underbrace{\frac{\text{yr.}}{\text{ht.d.d.}}}_{\text{heating degree days.}}$$

Additional information needed, or needed to be assumed, to solve the equation includes: sulfur content of oil, location of the new source (because of differences in heating/cooling degree days), air conditioner operating hours, and so forth.

Maps of heating and cooling degree days and air conditioner compressor operation hours were consulted (9) to choose representative areas of the country for analysis. A list of a sample of cities appears as Table 3. Five cities will be used for the analysis: Atlanta, Bismarck, Boston, Miami, and San Francisco.

The sulfur percentage of #2 fuel oil used for heating and the coal and oil used in power plants has to be assumed in order to

TABLE 3

LIST OF REPRESENTATIVE CITIES AND HEATING/COOLING PARAMETERS

Cities	Heating Degree Day	Compressor Operating Hour	Cooling Degree Day
Albuquerque	5000	600	1000
Atlanta*	3000	1600	1400
Bismarck*	9000	300	500
Boston*	6000	400	500
Chicago	6500	600	700
Denver	6500	200	500
Lincoln	6000	1000	1000
Los Angeles	2000	500	1000
Miami*	100	2500	4000
Missoula	9000	100	500
New Orleans	1500	2000	2700
New York	5500	700	1000
Okla. City	3500	1700	2000
Philadelphia	5000	850	1000
Portland	7500	300	500
Raleigh	3000	1300	1500
Reno	6500	500	500
Salt Lake	6000	100	1000
San Antonia	1500	2500	3000
San Diego	1500	500	1000
San Francisco*	3000	100	500
Seattle	5800	100	500
St. Louis	4500	1200	1400
Washington	4500	1000	1000

---

*Cities chosen for further analysis.

estimate sulfur oxide emissions. The percentages used for the three items listed in the previous sentence are 0.5%, 2.0%, and 1.0%, respectively.

Using the above assumptions and locations, emissions from land uses can be derived for the eleven land use types listed earlier. Presenting data for all these types would require a lot of space, so only one example will be given. It focuses on calculating SO_x emissions for "single family residences" (1600 square feet in area) having three different energy supply combinations: all gas, all electric, and part oil and part electric.* The results are presented in Table 4.

Both "Direct" and "Indirect" emissions are given in Table 1. Direct emissions are those at the residence itself, while indirect emissions are those at the power plant supplying electricity to the house. Indirect emissions are further divided into emissions from oil burning power plants (Oil) and coal burning power plants (Coal). Indirect emission factors are found in Table 2.

Multiplying emission factors times the appropriate "measure" results in an estimate of total yearly SO_x emissions. For the five

---

*An all gas residence uses natural or synthetic gas for space heating and cooling, hot water, and cooking. The last two uses are considered to be "processes," resulting in process emissions. See the emission factors tables. (All other process emissions are called miscellaneous emissions, and these are utility plant emissions associated with the residence's demand for electrical energy to run appliances, lights, etc.) An all electric house uses electrical energy for space heating and cooling, cooking, hot water, and processes. Emissions from an all electric residence are all indirect. A part oil-part electric residence uses #2 fuel oil for space heating and electricity for everything else.

TABLE 4

SO_x EMISSIONS FROM SINGLE FAMILY RESIDENCES

(Pounds of Sulfur Oxide Emissions Per Dwelling Unit Per Measure)

		All Gas	All Electric	Part Oil/Part Electric	Measure
Space Heating					
Direct		.00002	--	.016	Heating Degree Day
Indirect:	Oil	--	.04788	--	Heating Degree Day
	Coal	--	.11628	--	Heating Degree Day
Space Cooling					
Direct		.00001	--	--	Compressor Operating Hours
Indirect:	Oil	--	.05922	.05922	Compressor Operating Hours
	Coal	--	.14382	.14382	Compressor Operating Hours
Process					
Direct		.41	--	--	Year
Indirect:	Oil	99.54	320.04	320.04	Year
	Coal	241.74	777.24	777.24	Year

Note: Total Yearly Emissions = (Space Heating Emissions)(Heating Degree Day) + (Space Cooling Emissions)× (Compressor Operating Hours) + (Process Emissions)(Year).

cities previously chosen, estimated total direct yearly SO_x emissions for a single family residence are presented in Table 5. Also given in the Table is the number of dwelling units needed before a 50 ton new source review is triggered; the number should be doubled for a 100 ton new source review.

If both direct and indirect emissions of a residence are considered, then the New Source Review triggering point reduces dramatically, as shown in Table 6. The seemingly anomolous results in the Table, where SO_x emissions for a single family residence are higher in warm areas than in (moderately) cold ones, is due to the very high indirect emissions rates caused by operating air conditioner compressors. Because this rate is 2.5 times higher for coal fired power plants than oil fired plants, a high number of compressor hours (such as in Miami and Atlanta) causes some changes in emissions ranking among areas depending on type of fuel burned in the plant.

It should be reemphasized that the emission estimated are for uncontrolled emissions. Because most power plants control SO_x emissions to some extent, the emission estimates and triggering level of New Source Review have to be changed to reflect the amount of emissions control realized in an area.

SUMMARY & CONCLUSIONS

Land use based emission factors were presented for single family residences (area sources). The factors were applied to a problem associated with EPA's evolving New Source Review policy,

TABLE 5

ESTIMATED DIRECT TOTAL YEARLY SO_x EMISSIONS FOR A SINGLE FAMILY RESIDENCE IN FIVE CITIES AROUND THE COUNTRY

City	SO_x Emissions (Pounds $Year^{-1}$)	Number of DUs Needed Before a 50 Ton NS Review is Triggered
Atlanta		
All Gas	0.49	204,081
All Electric	--	N.A.
Part Oil, Electric	48.00	2,083
Bismarck		
All Gas	0.59	169,491
All Electric	--	N.A.
Part Oil, Electric	144.00	694
Boston		
All Gas	0.53	188,679
All Electric	--	N.A.
Part Oil, Electric	96.00	62,500
Miami		
All Gas	0.44	227,272
All Electric	--	N.A.
Part Oil, Electric	1.60	62,500
San Francisco		
All Gas	0.47	212,765
All Electric	--	N.A.
Part Oil, Electric	48.00	2,083

N.A. = New Source review is not applicable (an infinite trigger).

DUs = Dwelling Units.

TABLE 6

ESTIMATED DIRECT AND INDIRECT TOTAL YEARLY SO_x EMISSIONS FOR A SINGLE FAMILY RESIDENCE USING OIL HEAT IN FIVE CITIES AROUND THE COUNTRY

City	SO_x Emissions (Pounds Year $^{-1}$)	Number of DUs Needed Before a 50 Ton NA Review is Required
Atlanta		
Oil PP	462.79	216
Coal PP	1,055.35	94
Bismarck		
Oil PP	481.81	207
Coal PP	964.39	103
Boston		
Oil PP	439.73	227
Coal PP	930.77	107
Miami		
Oil PP	469.69	212
Coal PP	1,138.39	87
San Francisco		
Oil PP	373.96	267
Coal PP	839.62	119

Note: PP stands for power plant.
DUs = Dwelling Units
Total Yearly Direct and Indirect Emissions = Direct Emissions + Indirect Emissions + (Compressor Operating Hours) (Indirect Space Cooling Emission Factor).

and were found to be both tedious and easy to use in practice. The tedium comes from the numerous steps involved in computing emissions for a particular location for particular assumptions. There may be a way to simplify the process some, but it is felt that combining components or otherwise reducing the steps may result in too large an error in estimate. The amount of labor involved in using land use emission factors is still less than that needed to develop a typical area source emission inventory. Also, the units and organization of the factors are familiar to urban planners, which means that they probably will use the factors more readily than, say, fuel use factors.

While the factors have not been compared to other emissions estimating procedures, the extensive use of disaggregated engineering estimates and actual samples of energy consumption gives the authors a lot of confidence in the factors. However, it is recognized that a validation of land use based emission factors is in order.

The application of land use based emission factors to a new source review illustrate their convenience and applicability with project level data -- especially with planned projects whose characteristics are still vague. They are also expected to be useful in reviewing community or municipal scale plans and programs -- situations where convential emission inventory techniques are awkward or impractical to use.

The land use based emission factors presented in this paper have been applied successfully in the following situations.

- To estimate the stationary source CO emissions in an indirect source air quality evaluation.
- To estimate the sulfur oxide and particulate emissions from development in the corridor associated with a relocated major urban arterial highway.
- To evaluate energy consumption associated with several alternate plans for a two city block urban renewal project.
- To estimate residential emissions in an environmental impact statement for a residential development.

REFERENCES

1. Office of Air Quality Planning and Standards. Guidelines for Air Quality Maintenance Planning and Analysis. Research Triangle Park, North Carolina: Environmental Protection Agency. Volume 7: Projecting County Emissions (1975), EPA-450/4-74-008; Volume 13: Allocating Projected Emissions to Sub-County Areas (1974), EPA-450/4-74-014; "Accounting for New Source Performance Standards in Projecting and Allocating Emissions--Hypothetical Example" (1975), a supplement to Volume 13; and Volume 13: Appendices A and B (1975); EPA-450/4-74-014a.

2. Richard R. Cirillo and Michael J. Senew. Development of Computerized Emmissions Projection and Allocation System--Phase I: Preliminary Feasibility Study. Research Triangle Park, North Carolina: Environmental Protection Agency, (EPA-450/3-77-001).

3. Peter C. Cosier, IV. "Land Use Based Emission Stretegies: Their Promise and Problems", Planning Comment (November 1976) 12:31-48.

4. A. S. Kennedy, et al. Air Pollution Land Use Planning Project; Volume II: Methods for Predicting Air Pollution Concentrations from Land Use. Research Triangle Park, North Carolina: Environmental Protection Agency, 1973. (EPA-450/3-74-028b)

5. John C. Goodrich. Hackensack Meadowlands Air Pollution Study-Emission Projection Methodology. Research Triangle Park, North Carolina: Environmental Protection Agency, 1973. (EPA-450/3-74-56b)

6. Bill Swindaman. "Notes on Land Use Based Emission Factors", Unpublished paper available at the Land Use Planning Office, Strategies and Air Standards Division, U.S. Environmental Protection Agency, June 1972.

7. Thomas E. Baldwin and Allen S. Kennedy. "The Feasibility of Predicting Point Source Emissions Using Industrial Land Use Variables: A Path Analysis", presented at the 67th Annual Meeting of the Air Pollution Control Association, 1974. (APCA paper #74-145)

8. John C. Goodrich and Byron H. Willis. "A Methodology for Determining Emissions from Land Use Planning Data", presented at the 65th Annual Meeting of the Air Pollution Control Association, 1972. (APCA paper #72-122)

9. Frank Benesh. *Growth Effects of Major Land Use Projects; Volume II--Compilation of Land Use Based Emission Factors*. Research Triangle Park, North Carolina: Environmental Protection Agency, 1976. (EPA-450/3-76-012b)

10. J. Ross McKeever (ed.). *The Community Builders Handbook*. Washington, D.C.: Urban Land Institute, 1968.

11. Office of Air Quality Planning and Standards. *Compilation of Air Pollutant Emission Factors*. 2nd Edition. Research Triangle Park, North Carolina: U.S. Environmental Protection Agency, April 1973, and supplements. (AP-42)

12. See, for example, the *Keystone Coal Industry Manual*. New York: Mining Information Services of McGraw Hill, 1969.

13. James Couillard. *Browns Directory of North American Gas Companies*. Duluth, Minnesota: Harcourt Brach Jovanovich, 1973.

14. Arthur D. Little, Inc. *Project Independence Blueprint: Volume I*. Washington, D.C.: Federal Energy Administration, 1974.

15. Marketing Division. *Residential Appliance Gas Consumption, Phase 4.* Lincoln, Nebraska: Northern Natural Gas Company, 1973.

16. R. Anderson. *Residential Energy Consumption: Single Family Housing Final Report*. Washington, D.C.: U.S. Department of Housing and Urban Development, 1973.

17. American Gas Association. *Gas House Heating Survey (Annual)*. Arlington, Virginia: American Gas Association, various years.

18. American Gas Association. *Info Data Sheet: Use of Gas by Residential Appliances*. Arlington, Virginia: American Gas Association, 1971.

19. Hittman Associates. *Residential Energy Consumption--Multifamily Housing*. Washington, D.C.: U.S. Department of Housing and Urban Development, 1974.

20. Electric Heating Association. *EHA Case History*. New York: Electric Heating Association, various cases.

21. Gordian Associates. *Environmental Impact of Electric vs. Fossil Fuel Space Heating for the Welfare Island Development Project.* New York: New York State Urban Development Corporation, 1972.

22. H. Hansteen and J. Kirkwama. "The Fossil Electric Ratio", paper presented at the Annual Meeting for the American Society of Mechanical Engineers, 1968. (ASME paper #68-WA/PEM-3)

23. American Society of Heating, Refrigerating, and Air Conditioning Engineers. ASHRAE Heating, Ventilating, and Air Conditioning Guide. New York: ASHRAE, 1958.

24. Building Owners and Managers Association International. 1975 Office Building Experience Exchange Report for the Calendar Year 1974. Chicago: BOMA, 1975.

25. National Coal Association. Steam Electric Plant Factors. Washington, D.C.: NCA, 1973.

26. Edison Electric Institute. Statistical Yearbook of the Electric Utility Industry, New York: EEI, 1972.

27. Kenneth A. Hagg, et al. "Maintenance Planning in Massachusetts: Use of Land Cover Factors for Apportionment and Projection of Areas Source Emissions", paper presented at the 68th Annual Meeting of the Air Pollution Control Association, 1975. (APCA paper #75-22.8).

28. 41 Federal Register 246: 55558 (December 21, 1976). The notice is entitled "Review of New Sources and Nodifications" and is part of 40 CFR 51.

29. 41 Federal Register 246: 55524 (December 21, 1976). The notice is entitled "Air Quality Standards: Interpretative Ruling" and is related to 40 CFR 51.

30. Evaluation and Planning Division, California Air Resources Board. The Land Use/Oxidant Precursors Emissions Study(DRAFT). Sacramento, CA.: A.R.B., 1976.

CONDENSED DISCUSSION

QUESTION: On these housing developments; what new source review are you looking at from a standpoint that a new housing development will bring in new cars and put out new hydrocarbons and whether they should be subject to the new source review?

MC CURDY: That's an interesting question because under indirect source review you were supposed to have done that; but indirect source review as you probably know is dead for all types of land use except for highways and airports. This growth effects the major land use projects. It's specific aim was to develop a procedure where we can estimate the amount of secondary development caused by the construction and operation of major land use types. The first two types we looked at were residential development and industrial parks. You put in an industrial park and what happens to the urban structure around it? What happens to VMT, etc.? We have a simple predictive methodology which is based on multiple regression again, and we are quite high r^2's.

I was appalled at the r^2's that were mentioned earlier. Our's are .75 - .54. At any rate our office is looking into that. Right now we have a project to do exactly the same thing for sewage treatment plants. If you put in a sewage treatment plant, what is going to happen next? We are developing easy to use procedures so that if you knew what size treatment plant you had or what size inceptor you had, we could estimate the amount residential development induced by and associated with this major project. I don't think EPA is going to have a policy saying that you have to do this for all development types.

EMISSION RATES FOR BIOGENIC NO_x

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

Hilman C. Ratsch and David T. Tingey
Terrestrial Ecology Branch
Corvallis Environmental Research Laboratory
U. S. Environmental Protection Agency
Corvallis, Oregon 97330

Abstract

A literature review of biogenic sources of NO_x was conducted to determine their emission rates into the atmosphere. NO_x are some of the products of microbial denitrification, chemical decomposition of nitrites and the oxidation of organic nitrogen compounds. There appears to be no significant emission of NO_x from either oceans or freshwaters. Biogenic emission rates for NO and NO_2 from soil range from 0.015 to 0.02 kg NO km^{-2} hr^{-1} and 0.01 to 0.2 kg NO_2 km^{-2} hr^{-1}. Submerged soils, sediments, marshes and swamps could be sources of NO_x but emission data are not available. There is no significant evidence of NO_x emission from living vegetation. During decay, decomposition and ensiling of vegetation, NO_x can be formed. Although the emission rates are not known, they are probably not significant.

The estimates of NO_x emission rates from the above biogenic (soil) sources were computed for a global basis and then compared closely to previously estimated natural global emissions. Also, the background atmospheric concentrations of NO_x are similar to those levels predicted from biogenic emission rates.

Introduction

Several authors have estimated global biogenic NO_x emissions. Robinson and Robbins (1970) estimated global natural emissions of NO_x at 768×10^9 kg NO_2 which was approximately 15 times the anthropogenic emissions (53×10^9 kg NO_2). McConnell (1973) suggested that the natural sources of NO_x were 4 times the anthropogenic sources. Galbally (1975) estimated biogenic NO_x emissions for the northern hemisphere at 1×10^9 kg NO_2 yr^{-1} and the anthropogenic emissions at 0.5×10^9 kg NO_2 yr^{-1}. Estimates of biogenic emissions for NO_x for Ohio and surrounding states, ranged from 1.7 to 4.1×10^8 kg NO_2 yr^{-1} and the anthropogenic emissions ranged from 2.5 to 33.3×10^8 kg NO_2 yr^{-1} (RTI, 1974). These calculated NO_x emissions were based on atmospheric concentrations and a theoretical balance of nitrogen compounds. At present there is no general agreement on the relative contributions of the biogenic and anthropogenic emissions. Most biogenic emission rates were derived from the amounts of NO_x needed to balance nitrogen cycles or were deduced theoretically.

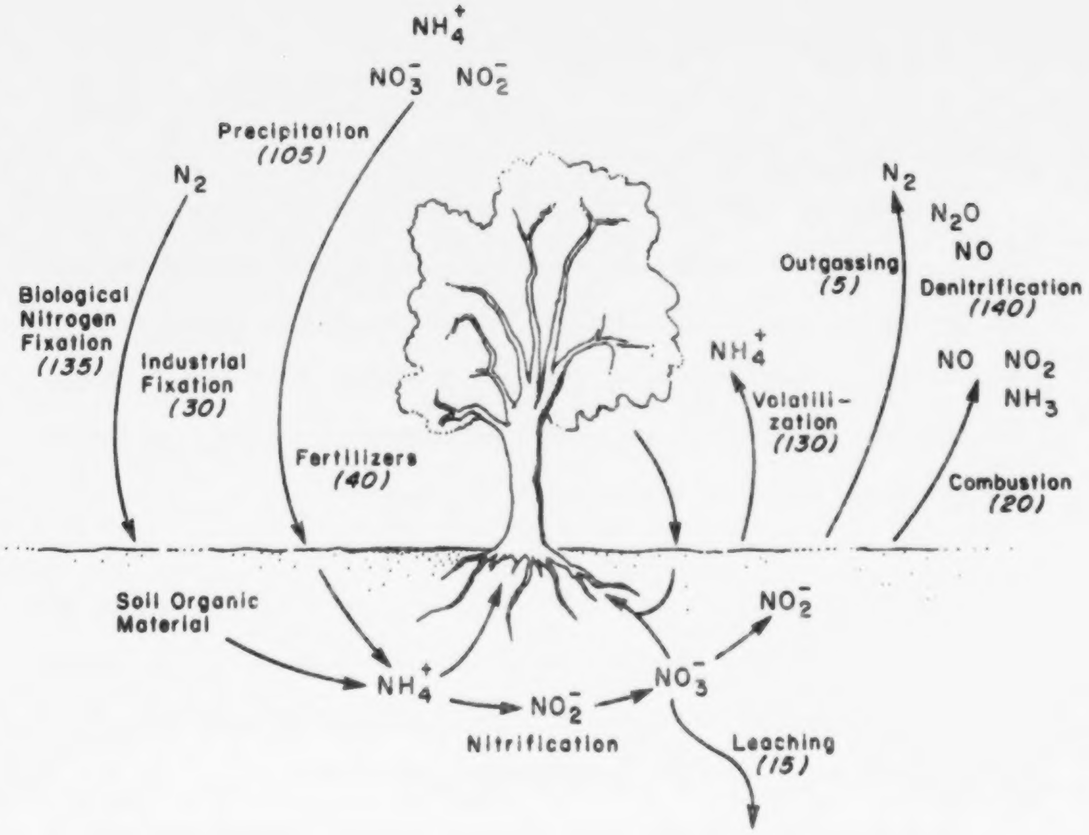
The objectives of this literature review were to gather information on possible biogenic sources of NO_x, to determine biogenic emission rates and to discuss the factors affecting NO_x emissions. The nitrogen cycle is discussed to suggest possible biogenic sources of nitrogen oxides. The biogenic sources and emission rates of NO_x are divided into the following categories: 1) water: ocean and freshwaters; 2) soil; 3) flooded soil, sediments, swamp and marsh; and 4) vegetation. The biogenic emission rates determined from the literature were compared to other emission estimates and atmospheric concentrations.

Nitrogen Cycle

Nitrogen is found in five major sinks in the biosphere: primary rocks, sedimentary rocks, the deep-sea sediment, the atmosphere, and the soil-water pool. Approximately 98% of the earth's nitrogen is in primary and sedimentary rocks, while the atmosphere contains about 2%; the deep-sea sediment and soil-water pool together contain less than a percent of the global nitrogen (Burns and Hardy, 1975).

In the atmosphere, N_2 is the major nitrogen constituent while nitrogen oxides (N_2O, NO, NO_2), NO_3^-, NO_2^-, NH_3, and NH_4^+ are present in the ppm range or less. The soil-water pool can contain a large amount of dissolved N_2. N_2O, NO, and NO_2 can also occur in soils for short time periods under specific environmental conditions.

A simplified nitrogen cycle showing nitrogen transformations in the soil-water pool and transfers between the soil-water pool and the atmosphere is shown in Figure 1. Nitrogen enters the soil-water pool through biological nitrogen fixation, industrial fixation, precipitation and application of fertilizers. Biological fixation reactions occur either in free-living organisms (i.e. Azotobacter) or in symbiotic plant-microbial associations (i.e. Rhizobium). Plants and microorganisms utilize NH_4^+, NO_3^-, and NO_2^- from the soil-water pool and nitrogen undergoes a multitude of chemical and biological transformations.



NH_4^+
NO_3^-
NO_2^-
Precipitation
(105)
N_2
Biological Nitrogen Fixation
(135)
Industrial Fixation
(30)
Fertilizers
(40)
N_2
N_2O
NO
Outgassing
(5)
Denitrification
(140)
NH_4^+
Volatilization
(130)
NO
NO_2
NH_3
Combustion
(20)
Soil Organic Material
NH_4^+
NO_2^-
NO_3^-
NO_2^-
Nitrification
Leaching
(15)

Fig 1. Terrestrial nitrogen cycle showing nitrogen transfer and transformations. Values given are metric tons (N) × 10^6 yr^{-1} (Burns and Hardy, 1975; Hardy and Havelka, 1975).

In nitrification (Figure 1), an aerobic process, ammonium is oxidized to nitrate.

$$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$$

Oxidation occurs mainly by the autotrophic bacteria of the Nitrobacteriacea. The genus Nitrosomonas oxidizes ammonium to nitrite and the genus Nitrobacter oxidizes nitrite to nitrate. Other microorganisms, including certain bacteria, molds and fungi, are capable of limited oxidation of nitrogen, but their contribution to nitrification is limited. The rapid nitrification of ammonium is important agriculturally, since fertilizer ammonium can be rapidly oxidized to nitrate and then lost from the soil by denitrification, leaching and chemical decomposition (Hauck, 1971).

In denitrification (Figure 1), an anaerobic metabolic process, nitrate is reduced sequentially to NO, N_2O or N_2.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O,\ N_2$$

The reduction is carried out by a diverse group of bacteria but the non spore formers such as Pseudomonoas, Micrococcus, and Achromobacter and spore-forming species of Bacillus are the principal denitrifiers.

Biogenic Sources of Nitrogen Oxides

Water

Oceans—

The nitrogen cycle in the oceans is complex in respect to the large geographical translocations of nitrogen and in species composition of micro- and macro-organisms (Dudgale, 1969). Theoretical models of nitrogen circulation in oceans and mass balances for marine nitrogen cycles indicate that inorganic nitrogen is removed or lost from the oceans (Yoshinari, 1976; Dugdale, 1969). Denitrification is a significant factor in loss of nitrogen from the marine environment, especially in oxygen-deficient waters. Goering and Cline (1970) determined that denitrification in raw seawater occurred in two stages. First, nitrate was reduced to nitrite, and second, the nitrite was further reduced, presumably to N_2. Nitrate^{15}-N added to water samples from the oxygen-deficient layer in the tropical Pacific resulted in the production of nitrite and N_2. Denitrification rates varied from 7-150 μg N/l/day depending on sample depth (Goering, 1968). Estimated denitrification losses in oxygen-deficient waters of the Black Sea ($7 \times 10^9 - 2 \times 10^{11}$ g N yr^{-1}) and Cariaco Trench (1×10^{10} g N yr^{-1}) were not significant compared to those in the eastern tropical North Pacific (1×10^{13} g N yr^{-1}) (Goering et al., 1973).

Patriquin and Knowles (1974) examined shallow-water marine sediments from several locations for denitrifiers and found that most of the bacteria that reduced nitrate to nitrite also reduced nitrite to gaseous nitrogen. Bacterial isolates varied considerably in the rate of N_2 production and N_2O reduction, and in accumulation of N_2O. Barbaree and Payne (1967) demonstrated that N_2O and very small quantities of NO were present transiently in the atmosphere over reaction mixtures containing cell-free extracts of *Pseudomonas perfectomarinus* cells.

The above data support the conclusion that denitrification is an active process in the oceans and that both N_2 and N_2O are products but there is no evidence of NO_x production in oceans.

Freshwater—

As in the oceans, denitrification in freshwaters is a significant factor in nitrogen loss. The nitrogen cycle and the fate of nitrogen in freshwaters has been reviewed recently (Keeney, 1973; Brezonik, 1973).

In lakes, denitrification occurs mainly in the oxygen depleted hypolimnic layers where inorganic nitrogen levels are at a minimum (Vollenweider, 1968). Denitrification rates in Smith Lake, Alaska, in water one meter below the ice were measured at 15 μg N/liter/day. Molecular nitrogen appeared to be the only significant product and NO and N_2O were not detected (Goering and Dugdale, 1966). Brezonik (1973) concluded that denitrification did not appear to be significant in Florida lakes. Of the 55 north central lakes sampled in Florida, only four developed anoxic conditions at the bottom and the nitrate concentrations in Florida lakes are typically low. Nitrogen is the only product of denitrification released in significant quantity, and seldom is NO or N_2O detected (Payne, 1973).

In addition to denitrification, there is the possibility of chemical decomposition of nitrite to produce gaseous nitrogen products. In some lakes, concentrations of polyphenolic substances (tannins, lignins, humic acid) are high and pH of water is acidic. Under these conditions the reaction of nitrous acid with organics could be important as a source of nitrogen oxides (Brezonik, 1973).

Soil

The soil is an open system from which various nitrogen forms volatilize into the atmosphere. As early as 1944, it was discovered that nitrous oxide was one of the constituents of soil air (Kriegel, 1944). Adel (1946, 1951) suggested that N_2O was produced in the soil and was the source of atmospheric N_2O. Arnold (1954) confirmed N_2O losses from the soil and Wijler and Delwiche (1954) found that N_2O was the major initial product of denitrification under some soil conditions, but also identified NO as an additional product. More recently, in addition to losses from denitrification, investigators have found that NO and NO_2 are produced by chemical reactions in soil involving HNO_2 and nitrite. (Reuss and Smith, 1965; Nelson and Bremner, 1970; Bollag, et al., 1973).

land uses investigated in the GEMLUP project are contained in Reference 9. The factors are presented in units of pounds of pollutant emitted per "measure" for oil and gas combustion. For electricity consumption, the factors are in terms of kilowatt-hours per "measure". The measure, depending on the activity involved, may be square foot of building floor area per heating degree day, dwelling unit per year, air conditioner operating hour, etc.

The quantity of secondary, i.e., offsite, emissions occuring due to electricity consumption depends on the nature of the local electric utility generating station. In developing an estimate of secondary emissions caused by a land use type, the local utility should be contacted to determine the proper emission rate. Default values for these emissions have been developed, however, and appear as Table 2. They come from data in references 11,25, and 26.

None of the tables present process emissions for industrial sources. The estimation and use of land use based emission factors for industry presents severe problems. The variation in emissions per square feet of industrial land area, and probably in industrial building area also, is great (4,7). Therefore, GEMLUP industrial emission factors only includes fuel combustion and treats these emissions like area source emissions in a typical emissions inventory. Process emissions have to be obtained separately and added to fuel use emissions.

TABLE 2

TYPICAL EMISSION FACTORS FOR ELECTRIC UTILITIES

	Pounds of pollutant emissions per kilowatt hour sold to customer				
	PM	SO_x	CO	HC	NO_x
coal	5.23×10^{-3}	$1.53 \times 10^{-2}S$	4.03×10^{-4}	1.21×10^{-4}	2.21×10^{-2}
oil	6.34×10^{-4}	$1.26 \times 10^{-2}S$	2.38×10^{-4}	1.58×10^{-4}	8.32×10^{-3}
gas	1.19×10^{-4}	7.13×10^{-6}	2.02×10^{-4}	1.19×10^{-5}	8.32×10^{-3}
	Kilograms of pollutant emissions per joule sold to customer (SI Units)				
	PM	SO_x	CO	HC	NO_x
coal	6.59×10^{-10}	$1.93 \times 10^{-9}S$	5.08×10^{-11}	1.52×10^{-11}	2.78×10^{-9}
oil	7.99×10^{-11}	$1.59 \times 10^{-9}S$	3.00×10^{-11}	1.99×10^{-11}	1.05×10^{-9}
gas	1.50×10^{-11}	8.98×10^{-13}	2.55×10^{-11}	1.50×10^{-12}	1.05×10^{-9}

Note: A 33.3% overall plant efficiency is assumed for coal fired plants [34].
A 31.6% overall plant efficiency is assumed for oil and gas fired plants [34].

A 10% transmission loss is assumed [35].

'S' and 'A' represent, respectively, the sulfur and ash percentage of fuel by weight.

APPLICATION OF LAND USE BASED EMISSION FACTORS: DETERMINING " MAJOR SOURCES" IN NON-ATTAINMENT AREAS

To illustrate how land use based emission factors can be used, a "real-life" example will be presented. On December 21, 1976 EPA issued "Requirements" (28) and an "Interpretative Ruling" (29) on the location of new sources within non-attainment areas. The Ruling states that a major new source may lcoate in an area with air quality problems only if stringent conditions can be met. The conditions are: emissions are controlled to the "greatest degree possible, "equivalent emission reductions will be obtained from existing sources, and progress toward attaining air quality standards will be achieved (41 FR 55525). A preconstruction review process of all sources emitting 100 tons of pollutant* per year or more (1,000 tons for carbon monoxide) is mandated to implement the ruling. If these "major" sources do not meet the three conditions mentioned above, a State is not allowed to issue a construction permit under 40 CFR 51.18 (41 FR 55525).

In the other Federal Register notice, EPA proposes to lower the "major source" definition down to 50 tons of pollutant* per year (500 tons for carbon monoxide) (41 FR 55559). In other words, facilities emitting 50 tons of most criteria pollutants will be required to undergo new source review and meet the stringent requirements.

---

*The pollutants of interest are particulate matter, sulfur oxides, nitrogen oxides, and non-methane hydrocarbons.

For a private developer of land, a question immediately arises: what size of project will trigger a new source review? Phrased another way, what is the biggest shopping center (or apartment house, etc.) a developer can build without emitting 50 tons per year of SO_x or TSP? Land use based emission factors can be used to answer these questions, and doing so constitutes the example to be shown in the remainder of this paper.

Basically, the answer is obtained by using Table 1 to solve the following simple equation (or ones similar to it):

$$\text{sq ft} = \frac{\text{50 tons}}{\text{yr}} \bullet \underbrace{\frac{\text{sq ft}}{\text{tons}} \bullet \underline{\text{ht.d.d.}}}_{\text{land use based emission factor}} \bullet \underbrace{\frac{\text{yr.}}{\text{ht.d.d.}}}_{\text{heating degree days.}}$$

Additional information needed, or needed to be assumed, to solve the equation includes: sulfur content of oil, location of the new source (because of differences in heating/cooling degree days), air conditioner operating hours, and so forth.

Maps of heating and cooling degree days and air conditioner compressor operation hours were consulted (9) to choose representative areas of the country for analysis. A list of a sample of cities appears as Table 3. Five cities will be used for the analysis: Atlanta, Bismarck, Boston, Miami, and San Francisco.

The sulfur percentage of #2 fuel oil used for heating and the coal and oil used in power plants has to be assumed in order to

TABLE 3

LIST OF REPRESENTATIVE CITIES AND HEATING/COOLING PARAMETERS

Cities	Heating Degree Day	Compressor Operating Hour	Cooling Degree Day
Albuquerque	5000	600	1000
Atlanta*	3000	1600	1400
Bismarck*	9000	300	500
Boston*	6000	400	500
Chicago	6500	600	700
Denver	6500	200	500
Lincoln	6000	1000	1000
Los Angeles	2000	500	1000
Miami*	100	2500	4000
Missoula	9000	100	500
New Orleans	1500	2000	2700
New York	5500	700	1000
Okla. City	3500	1700	2000
Philadelphia	5000	850	1000
Portland	7500	300	500
Raleigh	3000	1300	1500
Reno	6500	500	500
Salt Lake	6000	100	1000
San Antonia	1500	2500	3000
San Diego	1500	500	1000
San Francisco*	3000	100	500
Seattle	5800	100	500
St. Louis	4500	1200	1400
Washington	4500	1000	1000

---

*Cities chosen for further analysis.

estimate sulfur oxide emissions. The percentages used for the three items listed in the previous sentence are 0.5%, 2.0%, and 1.0%, respectively.

Using the above assumptions and locations, emissions from land uses can be derived for the eleven land use types listed earlier. Presenting data for all these types would require a lot of space, so only one example will be given. It focuses on calculating SO_x emissions for "single family residences" (1600 square feet in area) having three different energy supply combinations: all gas, all electric, and part oil and part electric.* The results are presented in Table 4.

Both "Direct" and "Indirect" emissions are given in Table 1. Direct emissions are those at the residence itself, while indirect emissions are those at the power plant supplying electricity to the house. Indirect emissions are further divided into emissions from oil burning power plants (Oil) and coal burning power plants (Coal). Indirect emission factors are found in Table 2.

Multiplying emission factors times the appropriate "measure" results in an estimate of total yearly SO_x emissions. For the five pH 6.0 and below (Van Cleemput, et al. 1976). The addition of a soil sterilant ($HgCl_2$) increased the rate of NO production. The important conclusions from this study were that under acid conditions significant amounts of N_2, N_2O and NO were formed. The production of NO under acid conditions with and without a sterilant suggested the self-decomposition of nitrous acid similar to what occurs in arable soils. However, the data are not adequate to calculate emission factors.

---

*An all gas residence uses natural or synthetic gas for space heating and cooling, hot water, and cooking. The last two uses are considered to be "processes," resulting in process emissions. See the emission factors tables. (All other process emissions are called miscellaneous emissions, and these are utility plant emissions associated with the residence's demand for electrical energy to run appliances, lights, etc.) An all electric house uses electrical energy for space heating and cooling, cooking, hot water, and processes. Emissions from an all electric residence are all indirect. A part oil-part electric residence uses #2 fuel oil for space heating and electricity for everything else.

Vegetation

Plant leaves and roots can absorb both reduced or oxidized forms of nitrogen from the environment and a relatively large concentration of nitrogen compounds are found in plants. However, there is no direct evidence that any of this nitrogen is emitted into the atmosphere as NO_x. In contrast during decomposition NO_x can be emitted into the atmosphere but its significance is not known. During the ensiling process high concentrations of nitrogen oxides can be emitted. In an unventilated silo or enclosure, NO and NO_2 can reach hazardous levels and such levels have accounted for several fatalities (Commins, et al., 1971; Scaletti, et al., 1960). In decomposition of plant products only a small fraction of total nitrogen losses from the system are attributed to denitrification. In an eastern mature hardwood forest, an estimated 3.6% of the total nitrogen flux was lost through denitrification processes (Mitchell, et al., 1975). Estimated denitrification rates of 0.17, 1.61 and 0.08 kg N ha^{-1} yr^{-1} were measured for branches, logs and litter (H layer), respectively (Todd, et al., 1975). It is conceivable that under some conditions small amounts of nitrogen oxides are emitted during litter decomposition. However, data on the emission rates from decomposition are lacking.

Estimates of Global NO_x Emission

The source of NO_x in the atmosphere is both anthropogenic and biogenic. Estimates of anthropogenic emissions of NO_x on a global basis are in good agreement as shown in Table 2. But the biogenic emissions are varied and are much more difficult to identify, measure, or estimate.

The biological and chemical transformations of nitrogen compounds in the soil appear to be the major source of NO_x. The estimates of NO_x emission rates from soil (Table 1) range from 0.01 - 0.2 kg N $km^{-2}hr^{-1}$. This rate computed on a global scale gives an emission from 3 to 58 x 10^9 kg N yr^{-1} and compares closely to the estimated global NO_x emissions by Galbally (1975) and Söderlund and Svensson (1976).

The background concentrations of NO and NO_2 reported by Rasmussen, et al. (1975) is about 0.3 - 2.5 $\mu g\ m^{-3}$ and 2 - 2.5 $\mu g\ m^{-3}$, respectively. Söderlund and Svensson (1976) reported background concentrations of NO_x to range from 0.5 - 7.5 $\mu g\ m^3$ (as NO_2) depending on geographical location. If it is assumed that background NO_x is in a steady state condition, then NO_x deposition must be balanced by NO_x

emission. The total wet and dry deposition of NO_x for the terrestrial system was estimated at 32 to 83 x 10^9 kg N yr^{-1} and for the aquatic system at 11 to 33 × 10^9 kg N yr^{-1} (Söderlund and Svensson, 1976). Peterson (1977) estimated that NO_x is removed by wet and dry deposition processes at about 0.04 kg N $km^{-2}hr^{-1}$. This value is similar to soil NO_x emission rates given in Table 1. Therefore, background concentrations of NO_x can be explained in large part by biogenic NO_x emissions.

Table 1. Nitrogen Oxide Flux From Soil

Soil or Medium	N Addition	Type N Oxide	kg/km^2/hr. Emission Rate	Reference
low humic Ordinary Chernozem	NH_4 NO_3 urea	NO	.015-.02	Getmanets, 1972
Chernozem Podzol	NH_4 NO_3 100 Kg. N/ha	NO	.006 .004	Borisova, et al., 1972
top soil from pine, oak, sod stand (sandy loam)	none	NO_2	pine 0.125 oak 0.07 sod 0.11	Kim, 1973
Sod- Podzolic	NH_4 NO_3	NO_2	0.01-0.2 comment: variation during the growing season	Makarov, 1969
Sod - Podzolic medium clay loam	urea 240 Kg/ha	NO_2	0.03-0.05	Makarov and Ignatova, 1964
raw humus in spruce stand (feather moss)	KNO_3 NH_4 NO_3 Ca $(NO_3)_2$ Al $(NO_3)_3$	*(NO+NO_2)	.018 .029 .035 .104	Mahendrappa, 1974
raw humus (sphagnum moss)	NH_4 NO_3 Ca $(NO_3)_2$ Al $(NO_3)_3$	*(NO+NO_2)	.012 .018 .035	Mahendrappa, 1974

* emission rate calculated as NO_2

Table 2. Estimates of Global NO_x Emission

Sources of NO_x (10^9 kg N yr^{-1})		References
Anthropogenic	Biogenic	
16	234	Robinson and Robbins, 1970
18	* 72	McConnell, 1973
15	20	Galbally, 1975
19	8-25	Söderlund and Svensson, 1976
	3-58	estimated from data in Table 1.

* natural sources estimated at 4 or more times the anthropogenic sources.

REFERENCES

Adel, A. 1946. A possible source of atmospheric N_2O. SCIENCE 103, 280.

Adel, A. 1951. Atmospheric nitrous oxide and the nitrogen cycle. SCIENCE 113, 624-625.

Arnold, P. W. 1954. Losses of nitrous oxide from soil. J. SOIL SCI. 5, 116-128.

Bailey, L. D. 1976. Effects of temperature and root on denitrification in a soil. CAN. J. SOIL SCI. 56, 79-87.

Barbaree, J. M. and Payne, W. J. 1967. Products of denitrification by a marine bacterium as revealed by gas chromotography. MAR. BIOL. 1, 136-139.

Bollag, J. M., Drzymala, S. and Kardos, L. T. 1973. Biological versus chemical nitrite decomposition in soil. SOIL SCI. 116, 44-50.

Borisova, N. N., Burtseva, S. N., Rodionov, V. N. and Kirpaneva, O. L. 1972. Determination of nitrogen losses from soil in the form of different oxides and ammonia under field conditions. SOV. SOIL SCI. (4), 540-546.

Bremner, J. M. and Nelson, D. W. 1968. Chemical decomposition of nitrite in soils. 9th TRANS. INT. CONGR. SOIL SCI. 2, 495-503.

Brezonik, P. L. 1973. Nitrogen sources and cycling in natural waters. EPA-660/3-73-002 Ecological Research Series, U. S. Environmental Protection Agency. p. 7-19.

Burford, J. R. and Bremner, J. M. 1975. Relationships between the denitrification capacities of soils and total, water-soluble and readily decomposable soil organic matter. SOIL BIOL. BIOCHEM. 7, 389-394.

Burns, R. C. and Hardy, R. W. F. 1975. Nitrogen fixation in bacteria and higher plants. Springer - Verlag, New York, 189 pp.

Cady, F. B. and Bartholomew, W. V. 1961. Influence of low pO_2 on denitrification processes and products. SOIL SCI. SOC. AM PROC. 25, 362-365.

CAST, 1976. Effect of increased nitrogen fixation on stratospheric ozone. Rep. 53. Iowa: Council for Agricultural Science and Technology, 33 pp.

Chen, R. L., Keeney, D. R., Konrad, J. G., Holding, A. J., and Graetz, D. H. 1972. Gas production in sediments of Lake Mendota, Wisc. J. ENVIRON. QUAL. 1(2), 155-158.

Chen, R. L., Keeney, D. R., Graetz, D. A. and Holding, A. J. 1972. Denitrification and nitrate reduction in Wisconsin lake sediments. J. ENVIRON. QUAL. 1(2), 158-162.

Commins, B. T., Raveney, F. J. and Jesson, M W. 1971. Toxic gases in tower silos. ANN. OCCUP. HYG. 14, 275-283.

Delwiche, C. C. and Bryan, B. A. 1976. Denitrification. ANN. REV. MICROBIOL. 30, 241-262.

Dugdale, R. C. 1969. The nitrogen cycle in the sea. BIOLOGY AND ECOLOGY OF NITROGEN. Conf. Proc. University of California, Davis, NAS, Washington, D. C. p. 16-18.

Engler, R. M. and Patrick, W. H. 1974. Nitrate removal from floodwater overlying flooded soils and sediments. J. ENVIRON. QUAL. 3(4), 409-413.

Galbally, I. E. 1975. Emission of oxides of nitrogen (NO_x) and ammonia from the earth's surface. TELLUS 27, 67-70.

Getmanets, A. Y. 1972. Loss of mineral fertilizer nitrogen from soil in gaseous form. SOVIET SOIL SCI. 4, 172-175.

Goering, J. J., Richards, F. A., Godispoti, L. A. and Dugdale, R. C. 1973. Fixation and denitrification in the ocean. In E. Ingerson (Ed.) Proc. Intern. Symp. Hydrogeochim. Biogeochem. Vol. II. Clarke, Co, Washington, D. C. pp 12-27.

Goering, J. J. 1968. Denitrification in the oxygen minimum layer of the eastern tropical Pacific ocean. DEEP SEA RES. 15, 157-164.

Goering, J. J. and Cline, J. D. 1970. A note on denitrification in seawater. LIMNOL OCEANOGR. 15, 306-309.

Goering, J. J. and Dudgale, V. A. 1966. Estimates of the rates of denitrification in a subarctic lake. LIMNOL. OCEANOGR. 11, 113-117.

Hardy, R. W. F. and Havelka, V. P. 1975. Nitrogen fixation research: a key to world food? SCIENCE L88, 633-643.

Hauck, R. D. 1971. Quantitative estimates of nitrogen-cycle processes. *Nitrogen-^{15} in soil plant studies*, (Int. Atomic Energy Agency, Vienna) pp. 65-80.

Keeney, D. R. 1973. The nitrogen cycle in sediment-water systems. J. ENVIRON. QUAL. 2(1), 15-29.

Kim, C. M. 1973. Influence of vegetation types on the intensity of ammonia and nitrogen dioxide liberation from the soil. SOIL BIOL. BIOCHEM. 5, 163-166.

Kriegel, M. W. 1944. Analysis for hydrocarbons in the presence of nitrous oxide. GEOPHYSICS 9, 447-462.

Lance, J. C. 1972. Nitrogen removal by soil mechanisms. J. WAT. POLLUT. CONT. FED. 44, 1352-1361.

Mahendrappa, M. K. 1974. Volatilization of oxides of nitrogen from nitrate-treated Black Spruce raw humus. SOIL SCI. SOC. AM. PROC. 38, 522-524.

Makarov, B. N. 1969. Liberation of nitrogen dioxide from soil. SOVIET SOIL SCI. 1, 20-25.

Makarov, B. N. and Ignatova, V. P. 1964. Losses of nitrogen from the soil in the gaseous form. SOVIET SOIL SCI. (4), 407-413.

McConnell, J. C. 1973. Atmospheric ammonia. J. GEOPHYS. RES. 75, 7812-7821.

Macgregor, A. N. and Keeney, D. R. 1973. Denitrification in lake sediments. ENVIRONMENTAL LETTERS 5(3), 175-181.

Mitchell, J. E., Waide, J. B. and Todd, R. L. 1975. A preliminary compartment model of the nitrogen cycle in a deciduous forest ecosystem. Mineral Cycling in S. E. Ecosystems. ERDA symposium series CONF-740513. p. 41-57.

Nelson, D. W. and Bremner, J. M. 1970. Role of soil minerals and metallic cations in nitrite decomposition and chemodenitrification in soils. SOIL. BIOL. BIOCHEM. 2, 1-8.

Nelson, D. W. and Bremner, J. M. 1970. Gaseous products of nitrite decomposition in soils. SOIL BIOL. BIOCHEM. 2, 203-215.

Nommick, H. and Thorin, J. 1971. Transformation of N-^{15} labelled nitrite and nitrate in forest raw humus during anaerobic incubation. *Nitrogen-^{15} in soil plant studies*, (Int. Atomic Energy Agency, Vienna) pp 369-381.

Patrick, W. H. and Mikkelsen, D. S. 1971. Plant nutrient behaviour in flooded soil. In Rinauer, R. C. (Ed.), *Fertilizer technology and use, Second Edition* SOIL SCI. SOC. of AMER. Madison, Wisc. 187-215.

Patriquin, D. G. and Knowles, R. 1974. Denitrifying bacteria in some shallow-water marine sediments, enumeration and gas production. CAN. J. MICROBIOL. 20(7), 1037-1041.

Payne, W. J. 1973. Reduction of nitrogenous oxides by microorganisms. BACTERIOL. REV. 37, 409-452.

Payne, W. J., and Riley, P. S. and Cox, C. D. 1971. Separate nitrite, nitric oxide, and nitrous oxide reducing fraction from *Pseudomonas perfectomarinus*. J. BACTERIOL. 106, 356-361.

Peterson, E. W. 1977. Wet and dry deposition: A synopsis containing estimates of deposition velocities for some pollutant and trace gases in the atmosphere. EPA. CERL-037. Corvallis Environmental Research Laboratory, Oregon.

Ponnamperuma, F. M. 1972. The chemistry of submerged soils. ADVAN. AGRON. 24, 65-71.

Porter, L. K. 1971. Techniques for the measurement of soil nitrogenous pollutants. Int. symposium on identification and measurement of environmental pollutants, Ottawa, Ontario, Canada. pp. 84-91.

Rasmussen, K. H., Taheri, M. and Kabel, R. L. 1975. Global emissions and natural processes for removal of gaseous pollutants. WATER, AIR and SOIL POLLUTION 4, 33-64.

Reddy, K. R. and Patrick, W. H. 1975. Effect of alternate aerobic and anaerobic conditions on redox potential, organic matter decomposition and nitrogen loss in a flooded soil. SOIL BIOL. BIOCHEM. 7, 87-94.

Renner, E. D. and Becker, G. E. 1970. Production of nitric oxide and nitrous oxide during denitrification by Corynebacterium nephridii. J. BACTERIOL. 101, 821-826.

Research Triangle Institute, 1974. Natural emissions of gaseous organic compounds and oxides of nitrogen in Ohio and surrounding states. EPA Contract 68-02-1096, Task 12, 13.

Reuss, J. O. and Smith, R. L. 1965. Chemical reactions of nitrites in acid soils. SOIL SCI. SOC. AM. PROC. 29, 267-270.

Robinson, E. and Robbins, R. C. 1970. Gaseous nitrogen compound pollutants from urban and natural sources. J. AIR POLL. CONTROL ASSOC. 20, 303-306.

Scaletti, J. V., Gates, C. E. Briggs, R. A. and Schuman, L. M. 1960. Nitrogen dioxide production from silage. I. Field survey. AGRON. J. 52, 369-372.

Stanford, G., Legg, J. D., Dziena, S. and Simpson, E. C. 1975. Denitrification and associated nitrogen transformations in soils. SOIL SCI. 120, 147-152.

Söderlund, R. and Svensson, B. H. 1976. Nitrogen, Phosphorus and Sulfur— Global Cycles. SCOPE Report 7. Ecol. Bull. (Stockholm) 22, 23-73.

Stefanson, R. C. 1972. Soil denitrification in sealed soil-plant systems. I. Effect of plants, soil water content and soil organic matter content. PLANT and SOIL 37, 113-127.

Steen, W. C. and Stojanovic, B. J. 1971. Nitric oxide volatilization from a calcareous soil and models aqueous solutions. SOIL SCI. SOC. AM. PROD 35, 277-282.

Stevenson, F. J., Harrison, R. M., Wetselaar, R., and Leeper, R. A. 1970. Nitrosation of soil organic matter. III. Nature of gases produced by reaction of nitrite with lignins, humic substances, and phenolic constituents under neutral and slightly acid conditions. SOIL SCI. SOC. AM. PROC. 34, 430-435.

Todd, R. L., Waide J. B. and Cornaby, B. W. 1975. Significance of biological nitrogen fixation and denitrification in a deciduous forest ecosystem. Mineral Cycling in S. E. Ecosystems. ERDA symposium seres CONF-740513. p. 729-735.

Van Cleemput, O., Patrick, W. H. and McIlhenny. 1976. Nitrite decomposition in flooded soil under different pH and redox potential conditions. SOIL SCI. SOC. AN. J. 40, 55-60.

Vollenweider, R. A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication, O.C.E.D. Report, DAS/CSI 68.27

Wijler, J. and Delwiche, C. C. 1954. Investigations on the denitrifying process in soil. PLANT SOIL 5, 155-169.

Wullstein, L. J. and Gilmour, C. M. 1966. Non- enzymatic formation of nitrogen gas. NATURE 210, 1150-1151.

Wullstein, L. H. and Gil mour, C. M. 1964. Non-enzymatic gaseous loss of nitrite from clay and soil systems. SOIL SCI. 97, 428-430.

Yoshinari, T. 1976. Nitrous oxide in the sea. MARINE CHEM. 4, 189-202.

CONDENSED DISCUSSION

QUESTION: Which data did you think was most accurate of that in the table?

TINSEY: Well I think our own is, but if you look honestly at them I think in reality they are all relatively suspect.

PROCEDURES FOR CONDUCTING HYDROCARBON EMISSION INVENTORIES OF BIOGENIC SOURCES AND SOME RESULTS OF RECENT INVESTIGATIONS

Presented at the 1977
Environmental Protection Agency
Emission Inventory/Factor Workshop
Raleigh, North Carolina - September 13-15, 1977

By

Pat Zimmerman
Assistant Environmental Scientist
Washington State University
Air Pollution Research Section
Pullman, Washington 99164

Introduction

All of us have enjoyed the smells of a thick pine forest or a blossoming orange grove. Few of us can forget majestic views of distant blue mountains.

Pollution from plants? Not likely. Plants manufacture oxygen and we all know how important oxygen is.

Rasmussen and Went were among the first to attempt to measure vegetation emissions (Rasmussen and Went 1965, Rasmussen 1972). Essentially all previous predictions of natural hydrocarbon emission rates have either been made by Rasmussen or based upon his early work. That early work established that natural sources can contribute hydrocarbons to ambient air and it postulated that the amounts of emissions may be quite large. Smog chamber studies showed that ozone could be generated when car exhaust was irradiated by sunlight. It was then found that a mixture of "natural" hydrocarbons, NO_x and sunlight could also produce ozone (Ripperton et al. 1967). During the same time period the technology to accurately monitor ozone levels on a routine continuous basis was developed. As monitoring systems expanded, agencies began reporting high ozone levels in rural areas well away from local anthropogenic sources of ozone precursors. Local, State and Federal officials in charge of maintaining specified oxidant levels were faced with the monstrous task of designing comprehensive and often very expensive strategies to control the emission of oxidant precursors. Detailed inventories of anthropogenic point and area sources were conducted so that the most effective control techniques could be employed. Yet the natural component - though known to exist and known to have a potential for ozone development - was ignored. No standardized technique for the evaluation of natural sources existed.

In 1976 the National Air Data Branch of the Environmental Protection Agency funded the Washington State University Air Pollution Research Section to develop a technique for the evaluation of natural organic emissions. Specifically the project objectives were:

1. To Develop a standardized sampling and analytical methodology
2. To develop emission factors for a limited number of species
3. To develop standardized emission inventory techniques
4. To develop preliminary nationwide emission estimates

Sample Methodology

A static/dynamic enclosure system was developed which satisfied the project objectives. In addition the technique is relatively simple, inexpensive and easily reproducible by other laboratories.

Basically, the method involves enclosing a portion of the vegetation of interest in a Teflon bag, sucking most of the ambient air out of the bag and thus collapsing the bag around the branch. A "background" sample of the air from the collapsed bag is then collected. The bag is then quickly filled with a known volume (60ℓ @ 10ℓ/min.) of air which is free of all hydrocarbons and has a controlled level of CO_2. After the bag is partially inflated, an "emission rate" sample is collected while zero air continues to flow into the enclosure at a rate slightly higher than the sample rate (≈ 2ℓ/min.). The total enclosure time is approximately 15 minutes. The emission rate is equal to the difference in the hydrocarbon content of the bag as measured in the emission rate sample minus the hydrocarbon content of the bag as measured in the background sample collected prior to inflation with zero air. This emission rate is then divided by some unit of foliage measurement such as by leaf biomass. The result is a raw emission rate of the units: micrograms emission per gram leaf biomass per hour (μg/g.hr).

To collect emission samples from vegetation the following equipment is needed:

1. A portable source of pure air which is hydrocarbon free and can be regulated to give a precise flow rate.
2. A vegetation enclosure which does not add to or take away from organic vegetation emissions.
3. A method to collect an air sample from the enclosure and to move it to a laboratory.

4. A temperature sensor to measure bag temperature and ambient air temperature.

The WSU sample train included an open-ended 110 x 150 cm Teflon bag (capacity ≈ 120ℓ) as an enclosure. A sample manifold (Fig. 1) provided flow control for the pure air entering the bag and sample leaving the bag. A metal bellows pump was used for the transfer of samples from the enclosure into 5.5ℓ electropolished stainless steel cannisters. Clean 1/8" (od) copper tubing or 1/8" od Teflon tubing was used for pure air and sample transfer lines. Figure 2 is a schematic drawing which illustrates the experimental design. The pure air was obtained by cryogenically compressing air purified by an Aadco pure air generator into empty medical oxygen cylinders. Other sources of clean air such as zero-grade air commercially available in high pressure cylinders, could probably be used. However, it would be important to conduct a blank analysis of each cylinder to determine the CO_2 concentration and hydrocarbon species present. An indoor outdoor thermometer was used to obtain the ambient air temperature and the enclosed air temperature simultaneously.

The emissions from the surface of soil/leaf litter can also be sampled with this basic setup plus some additional equipment. The additional equipment consists of a sealing ring and a stainless-steel bag collar (Fig. 3). The sealing ring is driven into the soil; the bag collar is then placed in the center of the sealing ring.

FIGURE 1

PORTABLE SAMPLE MANIFOLD

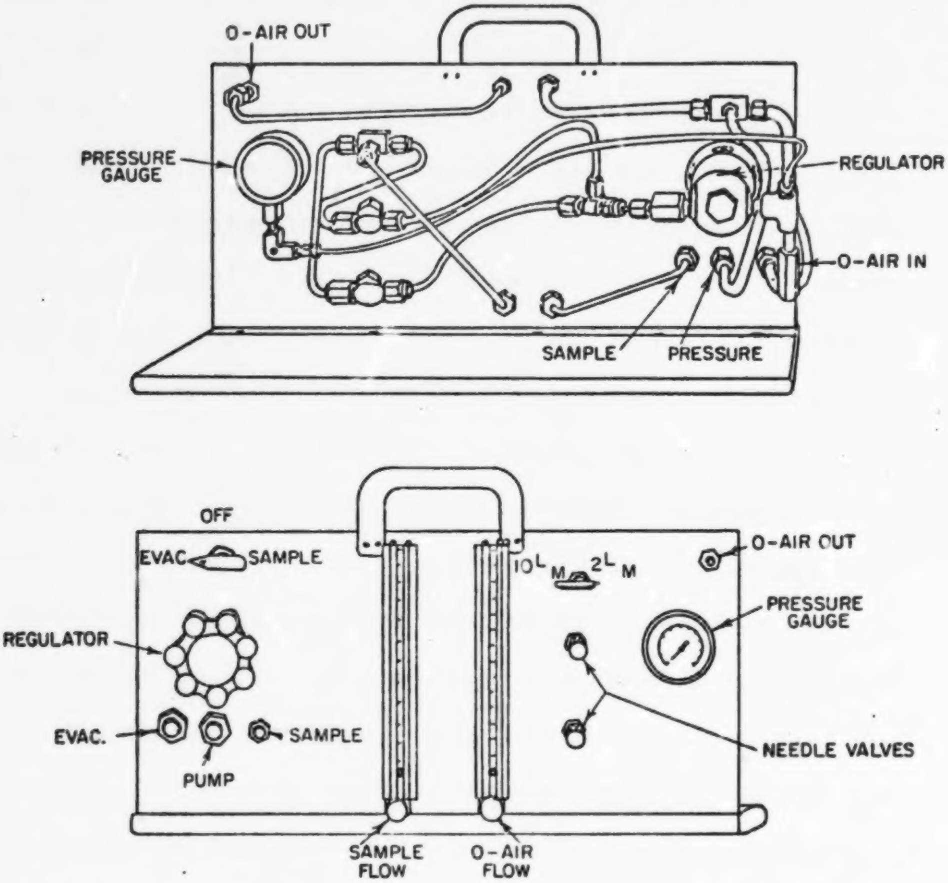

O-AIR OUT
PRESSURE GAUGE
REGULATOR
O-AIR IN
SAMPLE
PRESSURE
OFF
EVAC
SAMPLE
10 LM
2 LM
O-AIR OUT
REGULATOR
PRESSURE GAUGE
EVAC.
PUMP
SAMPLE
NEEDLE VALVES
SAMPLE FLOW
O-AIR FLOW

FIGURE 2

VEGETATION EMISSION SAMPLE COLLECTION SYSTEM

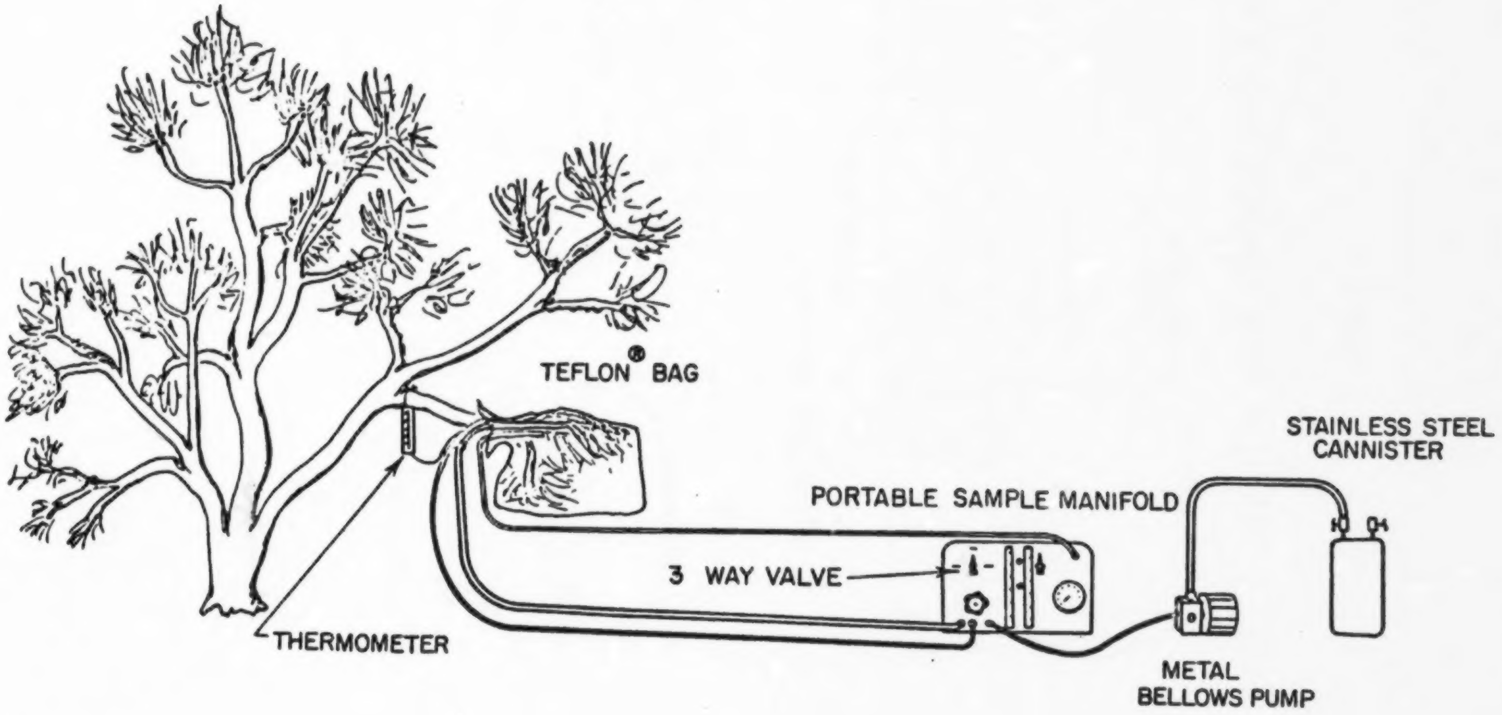
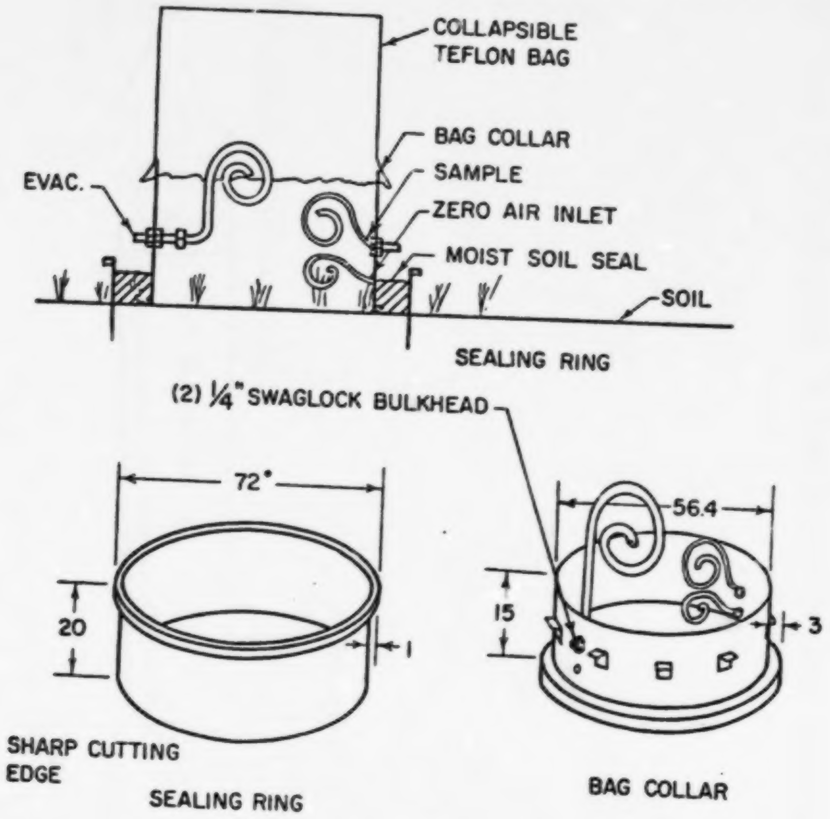

TEFLON® BAG
STAINLESS STEEL CANNISTER
PORTABLE SAMPLE MANIFOLD
3 WAY VALVE
THERMOMETER
METAL BELLOWS PUMP

FIGURE 3

SOIL LEAF-LITTER SAMPLING SYSTEM


COLLAPSIBLE TEFLON BAG
BAG COLLAR
SAMPLE
EVAC.
ZERO AIR INLET
MOIST SOIL SEAL
SOIL
SEALING RING
(2) ¼" SWAGLOCK BULKHEAD
72*
20
1
SHARP CUTTING EDGE
SEALING RING
56.4
15
3
BAG COLLAR

all dimensions in centimeters

Next moist dirt is used as a filler between the sealing ring and the bag collar. After the collar and ring are in place, the Teflon bag is attached by means of a wide elastic strap to the bag collar. The sample collection procedure is then identical to that for vegetation.

Surface waters of bays, estuaries and marshes can be sampled by the addition of a floatation ring to the bag collar. The WSU laboratory used two closed cell polyurethane filled water-ski belts sewn together and strapped around the bag collar as a floatation ring.

Analysis

Most samples were returned to the laboratory for f.i.d. gas chromatographic analysis within 24 hours. Columns and conditions are shown in Table 1. Three separate analysis were performed on each sample. One instrument was required to quantify methane, ethane, ethylene, and acetylene. Another instrument was equippped to quantify C_2 - C_6 hydrocarbons. A third instrument was commited to the analysis of C_4 - C_{12} hydrocarbons.

The overlap in analysis served as a check on GC performance. GC response was calibrated with respect to a standard concentration of neo-hexane.

In order to achieve sufficient GC response a sample concentration step is required. Prior to analysis, 500 ml of sample is drawn through a 3.2 mm (1/8") o.d. stainless steel sample loop

TABLE I

Hydrocarbon Analysis Conditions

Compound	Instrument		Operating Conditions
Ethylene Ethane Acetylene Methane	P.E. 3920 Isothermal FID	1.	Column: 10' x 1/8" OD Porapak Q Carrier: He 80 psi, 7 ml/min Hydrogen: 22 psig Compressed Air: 50 psig
Light Hydrocarbon C_2-C_6	P.E. 3920 Temp. Prog. FID	2.	Column: 20' x 1/16" OD Durapak N-Octane Carrier: He 90 psig, 6 ml/min Hydrogen: 40 psig Compressed Air: 50 psig Oven: Initial Temp. -70°C final 65"C Delay time: 4 min. Program rate: 16°/min Total Run Time: 40 min.
Heavy Hydrocarbon and Oxygenates C_4-C_{12}			Column: 10' x 1/8" Durapak Low K, Carbowax 400 Carrier: He 90 psig, 8 ml/min Hydrogen: 40 psig Compressed Air: 50 psig Oven: -20 to 100°C Delay Time: 2 min. Program Rate: 8°/min Total Run Time: 20 min.

TABLE 1 (cont'd)

Hydrocarbon Analysis Conditions

Heavy Hydrocarbon C_4-C_{12}	P.E. 3920 Temp. Prog. FID GC	4. Column: 200' SCOT OV-101, 10' x 1/16" OD Durapak low-K, Carbowax 400 precolumn Carrier: He 90 psig, 5 ml/min Hydrogen: 40 psig Compressed Air: 50 psig Oven: 0°C-100°C Temp. prog. Delay Time: 6 min. Program Rate: 6°/min Total Run Time: 60 min.
		5. Column: 30 m SE 30 Glass Capillary Column Carrier: He 90 psig, 1 ml/min Oven: -30-80°C Temp. prog. Delay Time: 8 min. Program Rate: 4°/min Total Run Time: 50 min.

attached to a six port sample valve. The loop is filled with 60 - 80 mesh glass beads and immersed in liquid oxygen. The sample valve is then switched on stream with the GC column and the loop is immersed in boiling water to flush the organics trapped on the glass beads onto the head of the column. Fig. 4 shows the vacuum sampling system used to introduce known amounts of sample into the sample loop. This system consists of a chamber of known internal volume which has been evacuated. A vacuum gauge is attached to the chamber and calibrated so that a specified change in vacuum is equivalent to a specified sample volume.

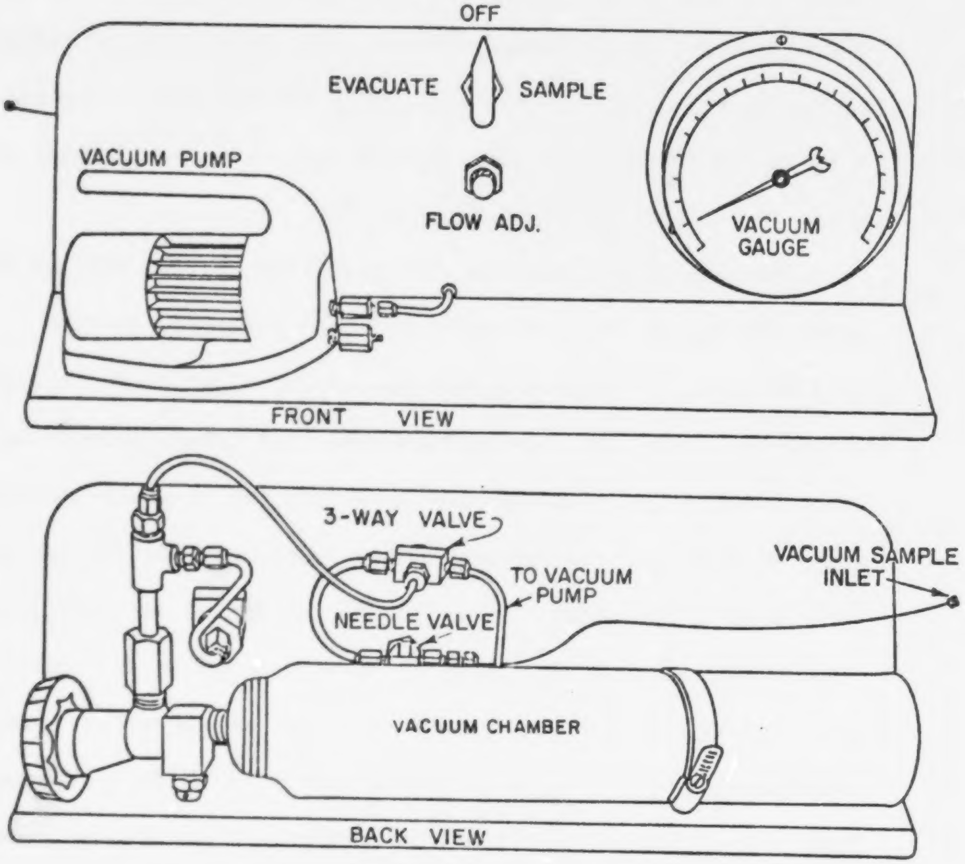
Preparation of an Emission Inventory

After a specific area and time period of interest have been designated for an emission-study program there are five major steps in developing an emission inventory.

1. Identify the major vegetation types and predominate plant species.
2. Select the representative species to be sampled.
3. Quantify the biomass for each species selected.
4. Conduct a field program to collect emission samples from each of the representative species.
5. Develop emission rate algorithums for seasonal and/or daily weather variables (sunlight, temperature, moisture).

FIGURE 4

VACUUM SYSTEM
for sample injection

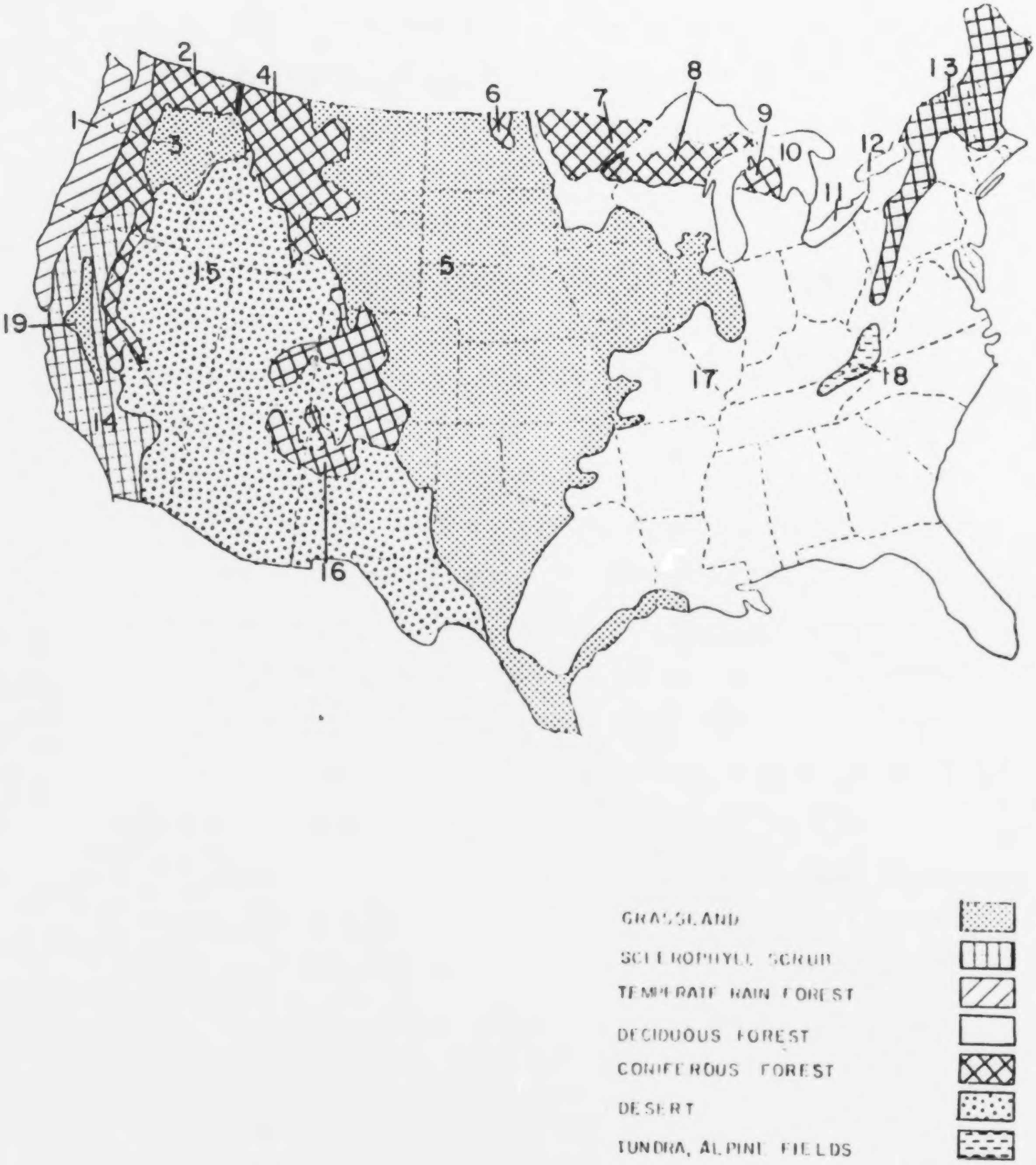

OFF
EVACUATE
SAMPLE
VACUUM PUMP
FLOW ADJ.
VACUUM
GAUGE
FRONT VIEW
3-WAY VALVE
TO VACUUM
PUMP
NEEDLE VALVE
VACUUM SAMPLE
INLET
VACUUM CHAMBER
BACK VIEW

These five steps can be classified into two basic components necessary for inventory development: 1) a set of emission factors representative of the vegetative species and conditions (season, temperature, etc.) for the area to be inventoried and 2) biomass factors, which are a measure of the quantity of vegetation or litter present in the area. Inventorying vegetation is therefore analogous to any other source category in that an appropriate emission factor is multiplied by some source activity level in order to estimate emissions.

The samples collected by WSU in Pullman in the fall of 1976 were used to construct a sample emission inventory for the continental U.S. Figure 5 is a map of the major biotic regions of the U.S. Raw emission factors were then determined for each biotic region by approximating the vegetative mix with the average emission rates of similar vegetation sampled in the Pullman area. The raw emission factors were then corrected for the effect of temperature. The temperature of the United States was approximated by an average winter temperature of 7.5°C and an average summer temperature of 23°C. The corrected raw emission factors were then multiplied by the respective summer and winter leaf biomass estimates for each biome. This resulted in an average summer emission factor and in an average winter emission factor. Multiplying these emission factors by the number of hours of summer and winter respectively and adding the products results in

Figure 5

MAJOR BIOTIC REGIONS OF THE U.S.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
GRASSLAND
SCLEROPHYLL SCRUB
TEMPERATE RAIN FOREST
DECIDUOUS FOREST
CONIFEROUS FOREST
DESERT
TUNDRA, ALPINE FIELDS

an estimation of the average annual emission rate from natural sources (Fig. 6). As figure 6 illustrates, this total is equal to aproximately four times the total emissions from anthropogenic sources. This emission inventory will be updated this fall. Recent sample programs conducted in Florida and North Carolina indicate that the emission factor used for oaks may be five times too small. Early samples were collected in a dark stainless steel enclosure. The major emission from oaks is isoprene and isoprene seems to be emitted almost exclusively in daylight conditions. Similarly samples of pines collected in Pullman had emission rates approximately one third lower than those of measured in North Carolina and Florida. These emission rate differences may partly be the result of species differences, but more likely the differences are due to seasonal changes in emission rates as reflected by the basic metabolic rate of the respective vegetation. Some raw emission rates for selected vegetation types sampled in Pullman, North Carolina and Florida are shown in Table 2. Figure 7 illustrates a preliminary emission inventory developed for the Tampa, St. Petersburg area. This inventory is also only an approximation. No area was subtracted for highways or developments and no provision for temperature or light relationships was included. Details of the inventory are explained in EPA Periodic letter Report IIV, Interim Progress Report, prepared for Air Programs Branch EPA Region IV, Contract -68-01-4432. Approximately

Figure 6

TOTAL YEARLY EMISSION RATE FOR THE CONTINENTAL U.S. BASED ON LEAF BIOMASS

Summer Emissions:

Average Vegetation Emission Rate

$1.36 \times 10^4 T/hr \times 708.7\ hrs/mo \times 5\ mo =$ $4.82 \times 10^7 T$

Litter Emission Rate

$132\ g/m^2\ hr \times 1 \times 10^6 m^2/km^2 \times 9.06 \times 10^6\ km^2/U.S. = 1.2 \times 10^3 T/hr$

$1.2 \times 10^3 T/hr \times 708.7\ hrs/mo \times 5\ mo =$ $\underline{4.20 \times 10^6 T}$

Total Summer Emission $5.24 \times 10^7 T$

Winter Emissions:

Average Winter Emission Rate

$7.04 \times 10^3 T/hr \times 708.7\ hrs \times 7\ mo =$ $\underline{3.49 \times 10^7 T}$

Total Yearly Emission Rate for Vegetation and Leaf-Litter $8.73 \times 10^7 T/yr$

Total Yearly Emission Rate from Anthropogenic Sources $2.12 \times 10^7 T/yr$

Natural Emissions as the Percent of the Total Emissions from All Sources

$$\frac{8.73 \times 10^7 T/yr}{2.12 \times 10^7 T/yr + 8.73 \times 10^7 T/yr} = 80\%$$

TABLE 2

AVERAGE RAW EMISSION RATES FOR SOME SELECTED SAMPLE TYPES IN FLORIDA
NORTH CAROLINA AND WASHINGTON

Sample Type	Number of Samples	$\overline{X}$ Raw Emission Rate
Tampa, Florida April - May 1977		
Selected Marine Samples		
Mud Flat	8	119.8 μg/m^2·hr
Intertidal Samples	3	117.2 μg/m^2·hr
Decaying Vegetation	13	202.0 μg/m^2·hr
Marine Grass	20	93.5 μg/m^2·hr
All Marine Samples	89	143.0 μg/m^2·hr
Pastures	32	288.6 μg/m^2·hr
Oaks		
Laurel Oak	10	11.2 μg/g·hr
Turkey Oak	3	26.1 μg/g·hr
Water Oak	3	27.2 μg/g·hr
Blue Jack Oak	6	16.5 μg/g·hr
All Species of Oak (Day)	25	21.14 μg/g·hr
All Species of Oak (Night)	3	1.20 μg/g·hr
Citrus		
Oranges	8	3.1 μg/g·hr
Grapefruit	3	2.8 μg/g·hr
Conifers		
Long Leaf Pine	16	3.3 μg/g·hr
Slash Pine	7	6.0 μg/g·hr
Sand Pine	2	7.3 μg/g·hr
All Conifers	26	5.1 μg/g·hr

TABLE 2 (cont'd)

AVERAGE RAW EMISSION RATES FOR SOME SELECTED SAMPLE TYPES IN FLORIDA NORTH CAROLINA AND WASHINGTON

Raleigh, North Carolina June 1977		
Oaks	3	26.10 μg/g·hr
Conifers		
Shortleaf Pine	2	16.3 μg/g·hr
Loblolly	2	4.85 μg/g·hr
E. Red Cedar	2	1.14 μg/g·hr
Virginia Pine	1	13.60 μg/g·hr
All Conifers	7	8.4 μg/g·hr
Pullman, Washington August - November 1976		
Conifers		
Ponderosa Pine	6	2.96 μg/g·hr
Mugo Pine	2	1.78 μg/g·hr
Douglas Fir	6	0.86 μg/g·hr
Juniper	4	3.25 μg/g·hr
Spruce	3	2.26 μg/g·hr
All Conifers	21	2.26 μg/g·hr
Oak (Dark Chamber)	2	4.40 μg/g·hr
Pine Litter	1	132.00 μg/m^2·hr

Figure 7

PRELIMINARY NATURAL HYDROCARBON EMISSION INVENTORY FOR THE TAMPA/ST. PETERSBURG AREA

Vegetation Type	Leaf Biomass Factor g/m^2	$\overline{X}$ Raw Emissions Factor $\mu g/g \cdot hr$	$\overline{X}$ Raw Emissions Rate $\mu g/m^2 \cdot hr$	Percent of area covered	Est. area Km^2	Total Emission Rate (g)/hr
Column	1	2	3	4	5	6
Tampa Bay Intertidal Marine Grass			143	22	997	$1.4X10^5$
Improved Pasture			284	9	419	$1.1X10^5$
Unimproved Pasture			301	12	558	$1.7X10^5$
Citrus	498	3.02	1,504	8	349	$5.2X10^5$
Mangrove	156	1.77	276	3	156	$4.3X10^4$
Palmetto	240	9.74	4,091	12	532	$2.2X10^6$
Pine	760	5.13	3,899	6	279	$1.1X10^6$
Shrubs	240	9.74	4,091	12	532	$2.2X10^6$

Figure 7 (cont'd)

PRELIMINARY NATURAL HYDROCARBON EMISSION INVENTORY FOR THE TAMPA/ST. PETERSBURG AREA

Oak-Hickory	498	14.87	7,405	8	349	$2.6\text{X}10^6$
Oak-Gum-Cypress	480	38.57	18,514	8	349	$6.5\text{X}10^6$
					4,520	$1.6\text{X}10^7$g/hr

Total Average Hourly Emission Rate	16T/hr
Study Area natural TNMHC Emission Rate: 16T/hr X 24hr/day	384T/day
Hillsborough County Anthropogenic Hydrocarbon Emission Rate	132T/day
Pinellas County Anthropogenic Hydrocarbon Emission Rate	48T/day*

*No official estimates were available for Pinellas County. This figure is a guess based upon the Tampa Bay (AQCR 052) NEDS emission rate estimate of 539T/day.

Percentage of TNMHC Burden Attribritable to Natural Sources: 384/180+384=68%

330 additional samples have been collected since tabulation of the preliminary Florida emission inventory. Considerable time has also been spent in better quantitation of the biomass in the study area. The final emission inventory will be available after March 1978 and will be included in an EPA computer modeling program which is intended to predict oxidant levels for the Tampa/St. Petersburg area.

Conclusion

Although all preliminary emission estimates predict that natural sources of hydrocarbons contribute significantly to the atmospheric burden, the actual concentration of natural hydrocarbons in ambient air is dependent upon the dilution volume relative to the hydrocarbon emission rate.

Westberg and Holdren (1976) reported on an analysis of monoterpenes from a rural forested site in northern Idaho by a gas chromatograph linked directly to a Mass Spectrometer. They collected samples of ambient air as well as vegetation emission samples using the Teflon bag enclosure technique described in this paper. The emission rates for the terpene compounds were then used to calculate expected ambient air terpene concentrations within the forest canopy. Their calculations show that assuming an average terpene emission rate of 3120 $\mu g/m^2 \cdot hr$ (obtained for a coniferous forest of this region) and a typical canopy height of 20 meters, 3120 μg of terpene compounds are emitted into a volume unit 1 meter x 1 meter x 20 meters (20 m^3) in one hour. The time (t) for the forest canopy to vertically exchange its volume can be calculated utilizing the "random walk assumption" which states that $T \simeq Z/2D$, where Z is the mixing distance (20 m) and D is the vertical diffusion coefficient in a forest canopy (assumed to be 10^4 cm^2/sec). Using these values the time for vertical exchange was calculated to be 200 seconds. The expected ambient air concentration within the canopy is then:

$$\frac{3120\ \mu g}{20\ m^3 hr} \times 200\ \text{sec} \times \frac{1\ hr}{3600\ \text{sec}} \times \frac{1\ ppb}{5.56\ \mu g/m^3} = 1.6\ \text{ppb total terpene conc.}$$

The calculated value of 1.6 ppb agrees relatively well with the ambient air values measured during the course of the Westberg-Holdren study. This calculation indicates that low levels of natural hydrocarbons are expected in ambient air and that normal dilution processes can account for these low levels. Thus, although an annual U.S. emission rate of natural hydrocarbons which is four times the total of all anthropogenic sources seems quite large, the actual concentration of natural hydrocarbons in ambient air is expected to be quite low. These low levels can be attributed to the diffuse nature of the source and natural dilution.

Another approach which can be used to put natural hydrocarbon emissions into perspective is to compare emission densities from vegetation and from anthropogenic sources in urban areas. Tom Lahre, Engineer for the Air Management and Technology Branch of the Environmental Protection Agency has used this approach to compare natural emission data generated by this study to data for anthropogenic emissions gathered during the NEDS program (personal communication).

Mr. Lahre's comparison shows that for the St. Louis urban and suburban areas (a radius of 22 miles from the center of the city) vegetative emissions comprise only 6% of the total of all emissions in the developed part of the city. However the ratio of the emission densities for Natural and Anthropogenic sources reaches unity if a radius of 68 miles from the center of the city is used. That is for the St. Louis area, assuming that the air were evenly mixed within a 68 mile radius of the city, 50% of the total hydrocarbon burden would be due to biogenic sources.

From this information it appears that the total of natural hydrocarbon emissions is large with respect to anthropogenic emissions, however anthropogenic sources tend to be much more concentrated and that physical dilution of natural hydrocarbon emissions can account for the low levels of natural hydrocarbons observed in rural areas.

Laboratory research has demonstrated that the natural emission products are very reactive both in photochemical processes and ozonolysis reactions. However it has also been reported that laboratory ozonolysis experiments typically required from 10 to 30 ppb of carbon from the terpene compounds to produce 1 ppb of ozone. In addition it has been predicted that many of the natural hydrocarbons would react with ozone very quickly after entering the atmosphere leaving only small quantities to exist long enough to participate in photochemical processes (Westberg 1977).

Though the information generated by the research is important a few researchers do not feel that it is conclusive. They point out, for example that most previous estimates of the ozone producing role of natural hydrocarbons are based upon a hydrocarbon mix of terpenes. They point out that our research has shown that in many areas isoprene is by far the largest natural emission product. Isoprene is very reactive photochemically and is not as likely to produce aerosols as the heavier terpenes. Also most bag irradiation experiments in which large amounts of particulates were formed were conducted at hydrocarbon levels much higher than those of rural ambient air. They believe that this would probably cause a shift in reaction kinetics as well as in the end products produced.

However a majority of previous research when coupled with the biogenic emission rate data determined by WSU indicates that biogenic emissions of natural hydrocarbons cannot in themselves account for the existence of high ozone levels in rural areas. Other mechanisms proposed to explain high ozone levels in rural areas include the direct injection of stratospheric ozone into the troposphere (Chatfield and Rasmussen, 1977), or the theory that anthropogenic ozone precursors including NO_x and man-made hydrocarbons are transported downwind over long distances, reacting to produce ozone. The relative importance of these mechanisms has not been determined.

Although natural hydrocarbon emissions do not seem to be the major cause of high rural ozone levels, it cannot be concluded that these emissions do not play a significant role in the chemistry of rural atmospheres. Recently much of the scientific literature has been focused upon the OH budget of the atmosphere. OH radicals seem to be very important in "scrubbing" trace gases such as SO_2, and chlorofluorocarbons from rural air. OH radicals are postulated as the reactive intermediates for many atmospheric reactions, including the formation of ozone (Wofsy 1976). They therefore have an effect on such far ranging problems as acid rain, stratospheric ozone depletion and tropospheric ozone production. The key to understanding these problems is a thorough understanding of the OH budget. One of the basic inputs of OH budget models is the hydrocarbon emission rate (including methane) into the atmosphere (Crutzen and Fishman 1977).

The interactions between stratospheric injection, downwind transport, the production of natural hydrocarbons and the OH budget are unknown. As a result the occurrance of high ozone levels in rural areas is not understood. Though many questions remain to be answered, determining the magnitude and types of biogenic emissions is an important step in understanding the air around us.

LITERATURE CITED

R. B. Chatfield and R. A. Rasmussen, "An Assessment of the Continental Lower Tropospheric Ozone Budget," EPA Report No. 700-1A-Jan., 1977.

R. J. Crutzen and J. Fishman, "Average Concentrations of OH in the Northern Troposphere, and Budgets of CH_4, CO and H_2," NOAA, Env. Res. Lab., Aeronomy Lab., Boulder, CO and NCAR, Air Qual. Div., Boulder, CO, 1977.

R. Rasmussen and F. W. Went, "Volatile Organic Material of Plant Origin in the Atmosphere," Proc. Nat. Acad. Sci., 53:215 (1965).

R. Rasmussen, "What do the Hydrocarbons from Trees Contribute to Air Pollution?" APCA Journal, 22, 537 (1972).

L. Ripperton, O. White and H. Jeffries, "Gas Phase Ozone-Pinene Reactions," Div. of Water, Air, and Waste Chemistry, 147th National Meeting American Chemical Society, Chicago, IL, pp 54-56. Sept. 1967.

H. Westberg, "The Issue of Natural Organic Emissions," prepared for U.S. EPA Office of Res. and Dev., order No. DA-7-1290J, 1977.

H. Westberg and M. Holdren, Quarterly Technical Report for EPA Grant No. 800670, J. Bufalini, Project OFficer, 1976.

S. C. Wofsy, "Interactions of CH_4 and CO in the Earth's Atmosphere, Ann Rev. Earth and Planetary Sciences, 4, 1976, pp 441-469.

Acknowlegements

This work was supported by the Following EPA Contracts:

Contract No. 68-02-2071 Title: Testing of Hydrocarbon Emissions From Vegetation and Development of a Methodology for Estimating Emission Rates from Foliage ion Any Geographical Area in the United States.

Contract No. Du-77-C063 Title: Additional Testing of Organic Emissions from Vegetation and Leaf Litter/Soil Surfaces.

Contract No. 68-01-4432 Title: Determination of Emission Rates of Hydrocarbons From Indigenous Species of Vegetation in the Tampa/St. Petersburg Florida Area.

Don Sterns, Phil Sweany and Bob Watkins provided significant contributions toward the successful completion of the fieldwork.

Disclaimer

The mention of specific brand names in this paper is solely for reference use, and does not constitute an endorsement by Washington State University or the Environmental Protection Agency.

CONDENSED DISCUSSION

QUESTION: Could you estimate what percentage of total is isoprene?

ZIMMERMAN: Isoprene has not been studied in bag studies. Isoprene is a very active ozone former and it doesn't tend to form particulates nearly as readily as the heavy organics. Most bag studies were also done at high concentrations. What that tends to do is favor the kinetics to produce particulates etc. I would say it depends on the forest. In a northwest forest, the isoprene concentration is lower. If you get back here where there are oak trees and other isoprene emiters, it would be higher. For an oak tree it is 99% of the total emissions. So, if you had all oak trees it would be 99%. But it is probably 60 or 70%, maybe as low as 50% in a mixed deciduous oak-hickory, etc. forest. Of course a lot of the oak-hickory areas that were shown on the map are actually loblolly pine now that the original forests have been cut down and replanted.

QUESTION: Will you report and try to break down the emissions by compounds.

ZIMMERMAN: The report for Florida will. This one won't as it is a survey report. We've got just what I presented. The one for Florida will have the emissions quantified by species for each one by one grid area. On an hourly basis throughout the day and throughout the season the major emissions will be pointed out.

QUESTION: Could you measure emissions over a diurnal cycle?

ZIMMERMAN: Yes, we did, day and night. Every four to six hours we would resample the live oak trees and pine trees and so forth.

QUESTION: Did you get no emissions from the Teflon sample bags?

ZIMMERMAN: It was pretty low because it was a short 15 minute enclosure time. We did background blanks. As long as we turn the bags inside out and let them dry out good between samples, background is low. It would also have been taken into account in our tests because we collected a background sample which would have included the bag emissions.

QUESTION: How did you investigate the possibility that by surrounding the branch with a bag you were changing its natural emissions?

ZIMMERMAN: What we tried to do was measure different parameters such as the bag temperature. We found in the very worse cases, if you put the bag in the sun it would heat up maybe 7 or 8 degrees F. We measured relative humidity, etc. That was the best we could do. We have also compared data with EPA people that are doing flux estimates.

I went through some of their figures and they came out pretty close. Anyway, it seems that at lower temperatures at least, there was a pretty good correlation.

QUESTION: Did you measure the CO_2 or did you add CO_2 to the bag?

ZIMMERMAN: Yes. We added CO_2 to the air that we put into the bag. We did measure it. We put in 365 parts per million, which is equivalent to ambient CO_2.

QUESTION: Did you check on the reduction of CO_2 as the reaction took place?

ZIMMERMAN: You mean did we measure it in the samples we collected? Yes, we did periodically. We didn't as a routine measure in Florida but when we were developing the technique we did. It didn't change a large amount, like 10% maybe. In the dark it would increase 10%.

QUESTION: You are talking about day and night sampling; did you sample in direct sun light and indirect sun light and were there any differences?

ZIMMERMAN: We sampled in all different lights. We recorded the cloud cover and so forth in the notes and we haven't gone through all the data yet so I can't make any strong correlations. In other words, I don't know where the isoprene emission peaks out with sunlight intensity. We can get that information from out data. We will determine a pattern when we refine our data more and more.